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MAGNETICAL

INVESTIGATIONS.

BY THE

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ETC. ETC.

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TO THE SECOND VOLUME.

As the present volume comprises investigations on a particular class of magnetical operations only—that belonging to TERRESTRIAL INDUCTION—it may be considered, as for the most part it certainly is, distinct and complete in itself. The subject has been elaborately elucidated, because it has been deemed—especially in its bearing on the navigation of iron-built ships—of national importance. If the views elicited differ essentially from those entertained by some men of distinguished attainments in science, the Author ventures to hope that the investigations and facts will not only maintain, but render inevitable, the conclusions, generally, which he has come to.

The former Parts of this work, as noticed in the Preface to the first volume, appeared at different periods; the first Part being published in the spring of the year 1839, and the second towards the close of 1843. These, with some alterations and additions, were connected and arranged as one volume in the following year. The third and fourth Parts of the series of Investigations, instead of being published separately like the others, have, because of the close

relation of the subjects, and the bearing of one on the other, been combined herein as a second volume. Though put to press in July 1851, the publication of the volume has been thus long delayed in consequence, partly, of a severe and dangerous accident happening to the Author, and on account partly, of various additions to the researches being found requisite, in order to the better connection and completeness of the two general divisions.

That the Author's early personal researches, in the branch of magnetical science from whence these have sprung, might appear in their due connection, he has been induced, herein, to refer to the records of years long gone by; and that original discoveries in magnetic principles, practical operations, or improvements in apparatus, may have a chance of being placed in the history of discovery according to their just claims, the dates of the researches, with the times and modes of publication, have been generally specified. If these matters have been stated somewhat particularly, it may be excused, it is hoped, on these personally-felt reasonable grounds,—that his improvements in compass-ne dles,—which, previous to the Author's suggestions and researches, were notoriously defective, and not unfrequently disgraceful as instruments,—have been adopted both by the public and for the Royal Navy; that his plans of testing the power and quality of compass-needles,—whereby a directive

energy, not only singularly permanent, but twice or thrice as great as that previously attained, was secured, — are said to be in use for the public service; that methods suggested by him in the former volume or previously, for the improvement of apparatus dependent on high degrees of energy and permanency of magnetism, have been very prevalently adopted both abroad and at home; and that, with but rare exceptions, these results of the Author's elaborate efforts and somewhat expensive researches have come beneficially into general use without either recognition or acknowledgment. From those indeed, who, as manufacturers of magnetical apparatus, have adopted what became publicly known as improvements, any particular acknowledgment was, perhaps, hardly to be expected; but from those who in conspicuous positions in the scientific world have found some reference to the improvements adopted unavoidable, better things might have been expected, than that their reference to such improvements should have been associated, as not unfrequently has been done, with the ungenerous endeavour to undervalue or eradicate the equitable claims of discovery by allusion to some former experiment or untested opinion, which, in whatever measure it might be supposed to be analogous, had unquestionably failed to produce any distinctive application until after the results of these personal researches had been publicly declared.

These remarks, which may seem to partake of the nature of complaint, have been unexpectedly suggested by the substance of the explanatory paragraph on which they follow; for an Author or discoverer, it is felt, gains ordinarily but a very defective measure of justice in undertaking, for himself, that which, in friendly hands, is at once so much more effective and graceful.

It only remains further to be noted, that, should health and opportunity, under Providence, be yielded to the Author, there are other portions of his researches, hitherto only occasionally touched upon, which he would hope, ultimately, to add to the present series. These, as indicated in the Preface to the primary volume, comprise PRACTICAL MAGNETICS, with the application of these Investigations to the improvement of Magnetical Instruments and Apparatus; various original illustrations of, and experiments on, Magnetical Principles and Phenomena; as also descriptions of original apparatus employed in the various departments of the Author's researches.

ATHENÆUM, *June 2nd*, 1852.

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MAGNETICAL INVESTIGATIONS.

PART III.

INVESTIGATIONS, WITH ILLUSTRATIVE EXPERIMENTS, ON THE NATURE AND PHENOMENA OF MAGNETIC INDUCTION, AND THE MUTUAL INFLUENCES OF MAGNETICAL BODIES.

CHAPTER I.

GENERAL VIEWS OF MAGNETICAL PHENOMENA, AND OF THE EARTH'S INDUCTIVE ACTION.

SECT. I.—*On the mysterious Source of Magnetical and Cognate Phenomena.*

MAGNETISM, to which our Investigations relate, is now well understood to be a principle of vast and essential operation in the general economy of nature. It is most intimately associated with electricity, caloric, and their kindred agencies.

The relation of these various mysterious agencies to each other, and their connection with a variety of physical phenomena, may be illustrated by reference to a simple experiment—that, for instance, of the ignition of a lucifer-match. In

this case the friction elicits chemical action of the nature of combustion. The development of light and heat, and the formation of a new combination of elements, are the obvious effects; but magnetism and electricity, though not ordinarily apparent, are as certainly developed.

Each of the principles herein noted as effects, may, in their turn, be made the originating cause in the development of the other phenomena. Thus, by means of electricity, we produce chemical change, with its consequents — magnetism, heat, light; by magnetic action, in like manner, we produce the corresponding or reciprocal results. So, also, by bringing chemical affinities into action, or simply by the influence of heat, we may develop the others. And, finally, by the action of light we have the more familiar effects of chemical change, with the production of heat, and, from the results obtained by Morichini and Mrs. Sommerville, it had been supposed (though the fact, under the particular mode of investigation adopted, is not generally considered, I believe, as conclusive) the development of magnetism likewise.*

Thus we have principles of singularly varied

* The want of conclusiveness of these results, as to the supposed magnetic effect of the violet rays of the sun, it need hardly be remarked, is no proof of the non-existence of magnetical powers in light, which, in some other form of experiment, will, not improbably, be yet demonstrated.

external characteristics mutually acting on one another, as, by way of illustration, the machinery of a clock, in its various parts, is mutually influential; for, detaching the pendulum, we give action to the whole series in combination, whatever particular wheel or pinion we cause to revolve.

We see no ground, therefore, for selecting any one quality as *primary* in the associate phenomena; much less for supposing that they are *all* primary or independent agencies. As to their essential character, they appear to be properties of something beyond; qualities or attributes of some unseen wondrous power. And such unknown power we conceive to be the essential master-principle and common parent of the various phenomena to which we refer.

In this view we must hold the opinion so frequently set forth since the celebrated discovery of Oersted, as to magnetism and electricity being *identical*, to be erroneous. We believe them to be essentially co-existent; but, because of incongruous properties, not, in the ordinary sense of the term, identical. For whilst one, by the interposition of certain substances, has its external influence intercepted, the other passes, without interruption, through all varieties of materials. In their action, too, they are very diverse. If considered as *forces*, they act tan-

gentially; if as *motion*, or *currents*, they run at right angles to each other.

Hence, the very prevalent deduction as to the identity of magnetism and electricity—because of their being reciprocally productive of each other and constantly associated — is not more necessarily true than the assumption that the kindred properties of life and sensation, in an organized being, or the various senses, associated with life and organization, are identical. Sensation, through the medium of organization, *results* from the mysterious master-principle of life; and the various senses, whilst subserving different objects, and being recipient of the action of different external influences, are attributes of the principle of life in organized beings, equally diverse from identity in themselves, as we deem electricity, magnetism, heat, etc. to be diverse and non-identical.

A very striking characteristic, varying however in its mode of operation, belongs to all the qualities of matter referred to, or, as they have commonly been designated, "imponderable elements," which is, *their power of acting at a distance* from the source of their individual development. Thus light and heat, where there is no interruption from opaque screens, extend their influence, in a determinate ratio of diminution with distance, far and wide. And the

effect of this influence is to imbue the objects by which their projected rays are arrested with their own essential qualities. So electricity and magnetism have their extraneous action on bodies beyond their respective sources. This action, however, becomes chiefly sensible, *under ordinary tests*, in particular substances; in substances, in the case of magnetism, being of a ferruginous nature, such being most eminently susceptible of magnetical qualities.

In all these imponderable influences there pertains an uniform law as to the ratio of their action with respect to distance, — the proportion of action being inversely as the squares of the distance: but a different law prevails in regard to the *manner* in which the influence is produced. In light and heat the influence, on extraneous objects, is effected by the radiation or abstraction of their own characteristic qualities; but, with electricity and magnetism it is not necessary, in order to an extraneous influence, that there should be any abstraction of the original quality.

Sect. II. — *General and Elementary Views of Induction.*

In the action of electrical and magnetical bodies, on bodies susceptible of the electrical or magnetical condition, we have elicited, in their

peculiar operation now referred to, the phenomenon of INDUCTION.

Magnetic induction consists not, strictly speaking, as the term might seem to indicate, in the communication of anything previously foreign to the ferruginous bodies in which the principle is elicited, as nothing is abstracted from the inducing magnet, and nothing in reality is infused into the iron thus magnetized. For in iron, as before intimated, the magnetic principle has evidently permanent residence,—capable, indeed, of exerting external influences, but not capable of being in reality abstracted or increased. Each portion and description of iron has its own constant and unalterable quantity, the two qualities of northern and southern polarity apparently existing in, or being essentially associated with, its individual particles. The usual and natural condition of the magnetisms is neutral. Yet the latent energies, especially in the softest kinds of iron and steel, are readily developed by the magnetic touch, or even by mere juxta-position of a magnetic body, or by the duly directed action of electricity. For though the natural quantity of inherent magnetism cannot be altered, yet an active and constant influence may be, and is, externally exerted, without any real loss to the actuating magnet, or, in any material degree, necessarily diminishing its original energy.

That the magnetisms reside inalienably in, or along with, their own particles of the metal, and are merely arranged in effective series by the magnetizing process, is satisfactorily, I think, indicated by this familiar experiment:—

[1. *Exp.*]*—Let a bar or plate of steel be magnetized, by any of the processes yielding a regular distribution of the influence, so that, when tried by its action throughout its length on a small magnetic needle held near it, one-half of the bar shall indicate northern and the other southern polarity, whilst the central part is neutral. In this case, were the magnetisms mobile in the mass, we should infer that the whole of each denomination of polarity had been gathered into its own section of the bar. But let the bar be broken in the middle, and we find, instead of obtaining the two polarities separately, that each half is now a complete magnet; that the two ends separated by the fracture, which, when in contact, were in a like neutral condition, are now of diverse magnetisms, and both of energetic polarity.

The same result is obtained, in the manner of Æpinus, by the arrangement of two, four, or

* The various experimental illustrations, as well as descriptions of apparatus and processes, are numbered throughout this part of our work in regular series, with a view to convenience in reference.

half-a-dozen corresponding steel bars, magnetized, as a single magnet, in a straight line. If the process has been properly effected, under a good contact of the ends, we shall have, as in the former case, the two polarities exhibited in the two halves of the series, with the neutral point in the middle. But, breaking the contact in the middle, we shall find the neutral point to have shifted,—the new ends, as before, having become *poles*, and the middle, or a part near the middle, of each segment, neutral. In the case of a four-bar series, another subdivision will yield, except as to degree of power of the now diminished magnets, the like results. There is a liability, indeed, under the ordinary modes of magnetizing steel bars in series, to have four or more poles produced instead of two only. But this defect, by an original process of magnetization hereafter described, is easily avoided.

Hence, we are led, naturally, I think, to the conclusion — That *INDUCED MAGNETISM consists in the development, by virtue of some extraneous magnetic influence, of the latent polarities in magnetizable bodies.* The actuating influence, we know, may be that of actual magnets, naturally or artificially produced; or it may be that of the earth's polarities; or it may consist in electro-magnetic or thermo-magnetic arrangements; or in simply electrical or chemical action. The

degree of capacity of different ferruginous bodies for magnetism by induction, is extremely various, being the smallest in the common iron-ores, and the greatest in the purest and most ductile iron.

These descriptions and considerations have been thought desirable to be adduced, as well as others subsequently given, familiar as in many respects they may be to the experienced magnetician, by the way of rendering the more original investigations and illustrative experiments, which follow, intelligible to the general reader, and at the same time for calling to mind such general principles as may serve for the connection or attachment of illustrations which otherwise might appear useless and insulated. And so, also, the succeeding descriptions relating to *the magnetism of position* are introduced by, and associated with, certain familiar explanations, because of the great variety of interesting and important phenomena which are dependent on this property of terrestrial magnetism.*

* The substance of the foregoing views, with a brief exposition of original researches on the nature and phenomena of magnetic induction, and of the mutual influences of magnets on each other, formed the subject of two communications to the British Association for the Promotion of Science, at its first meeting at York, Sept. 28th and 29th, 1831 (Report for 1831, p. 10). And, in a somewhat extended form, the same views were set forth and illustrated experimentally in lectures delivered, in London, at the Royal Institution and at the United Service Institution, in the year 1841.

It is in elementary and familiar things of nature, indeed (we may take occasion to remark), in which we have, ordinarily, the most *intelligible* displays of creative wisdom. And it is an important fact in the history of science, that the grandest discoveries and the noblest triumphs of human intelligence, in the natural world, have often had primary guidance from the *reflective consideration* of the facts and laws of the most common and obvious phenomena. Thus, the childish amusement of blowing soap-bubbles, the simple incident of the fall of an apple, and other things as familiar and common, have, under the development of master-minds, led to the determination of many of the grandest principles operating in nature, whereby the wonders of creation come to us in such beauty of light and colouring, and whereby the Great Architect of the heavens and the earth subordinates the vast masses of worlds and suns to the destiny appointed them by His sovereign will!

Every department indeed of creation is replete with manifestations of wisdom and power; and not the grander works in the heavens merely, but all the things of nature, were utterance given to them, would spontaneously urge the universal chorus—

"The hand that made us is Divine!"

We allude to, and describe therefore, the

elementary and familiar things belonging to our investigations, as at once most important in themselves, and as highly calculated to lead the rightly-ordered and enquiring mind beyond the things themselves to considerations respecting the Divine Originator of all, and respecting that great and blessed Redeemer, the head of the spiritual kingdom of the Godhead, by whom these and all things exist that were created and made.* For whilst the elementary phenomena of the natural world serve so well, in their universal use, to connect the creature with the Creator, there is, perhaps, no particular subject in natural science, which might, religiously contemplated, afford so many and useful illustrations of the sacred influences, sympathies, and operations of the Holy Spirit in man, as the influences, sympathies, and operations of that wonderfully penetrative and mysterious power by which the very interesting and wonderful phenomena of magnetism are produced.

Sect. III.—*General Effects of the Earth's Magnetical Influence.*

The general magnetical condition of the earth becomes, by virtue of the magnitude of the body with which the magnetism is associated, the grand

* John i. 3: Col. i. 16, 17: Heb. i. 1: Rev. iv. 11.

source or commanding agency both of the directive and inductive phenomena everywhere apparent. For wherever the exploring traveller has urged his way, there have these wondrous influences been marked; wherever the adventurous mariner has explored the extensions of the navigable ocean, there have the properties of the earth's magnetism availed for his guidance; wherever the laborious miner has penetrated the earth, there have the like influences been found unimpaired; and wherever the daring aeronaut has ascended into the atmosphere, thither have the magnetic phenomena been found to extend. The result, indeed, may be *inductive*, or it may be *directive*, according to the nature or condition of the ferruginous body on which the earth's action operates. Thus the inductive polarity of the earth acts on magnetizable substances, not being permanently magnetic, so as to develop in them a transient magnetic condition, and with a polarity of converse denomination (as to direction or parallelism) to its own; and thus the same influential polarity acts on substances already and permanently magnetic with a like *tendency*, but with the additional result, where the substance is delicately suspended and freely mobile, of adjusting the polarity of the mobile magnet into conformity, inversely as to the direction of the two poles, with the direction of the terrestrial

polarity. Thus the action of terrestrial magnetism, which, in the case of unmagnetic iron is indicated by the phenomenon of *induction*, appears, in the case of the mobile magnetic needle, in the result of *direction*.

We refer to this twofold action of terrestrial magnetism in the outset, because the inductive phenomena can be but very imperfectly explained or appreciated without the employment of the magnetic needle, which derives its directive property from the same source.

To Dr. Gilbert, of Colchester, who was physician in ordinary to Queen Elizabeth, we are indebted for the first enlightened views of the source of magnetical influence, and of the direction of the compass-needle, which he correctly ascribed to terrestrial magnetism.

The action of this influence, *inductively*, on metallic iron, of which we now particularly speak, is necessarily and essentially universal. In small portions of iron, and especially in non-elongated pieces and fragments, the influence may not be sufficiently energetic to render it appreciable; but in considerable bodies, and especially in bars or other elongated masses, the magnetic condition of iron, as developed inductively by the earth, is so considerable as to be easily detected; for if a *small* magnetic needle be used for the trial, both attraction and repulsion, the sure signs of existing

polarity, will always be found to be exerted, the degree of energy varying with the quality or description of iron, as well as with the form and the substance of the mass.

In bars, or large elongated masses of iron, in an upright position, this induced polarity is, in those regions where the direction of the earth's magnetism is far advanced towards the vertical, most conspicuous. Thus the upright bars of iron railings, or pillars, lamp-posts, etc., of iron, will affect a compass held near the top or base, with great energy, attracting the north pole of the needle at the upper part, and repelling it below; whilst large masses of iron, such as cannon, and vessels of extensive surface, such as steam-engine boilers, will exhibit the like effects, in regard to correspondence of position, at very considerable distances.

[2. *Experimental Illustration.*]—A familiar experiment, exhibiting the general phenomena of the energetic magnetism of upright bars, may be conveniently made with a common poker and any small magnetic needle or pocket compass. And it may here be generally noted that, for experiments of this kind, the *kitchen* poker will be found much more effective than that of the parlour, because of its being usually made of soft iron, whilst the latter, with a view to polish and

firmness, is invariably case-hardened or steeled throughout its surface.

Let the compass be placed very near to the edge of a table, on the *east* or *west* side of it, so that the direction of the needle is parallel to, or, in the case of a round table, parallel to the east or west tangent of, the proximate side of the table. Adjust the compass with its needle and north and south line in correspondence; and, holding the poker horizontally, in the direction of the east and west points of the compass, strike it a blow or two with a hammer, or other hard substance, to neutralize (as particularly described further on) any accidentally acquired magnetism therein.

The poker, whilst held in a vertical position, being now brought within three or four inches of the compass (east or west of its centre), will strongly attract the north pole, when the upper end is on a level with the compass, and repel the same pole when the lower end is raised to the same level—indicating southern polarity in the upper, and northern in the lower.

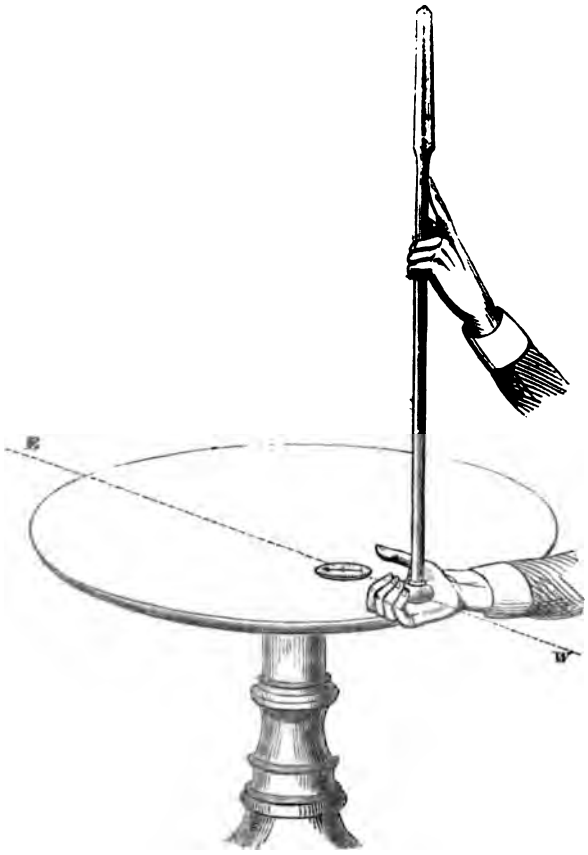
Inappropriate, we may here take occasion to remark, as is the designation of *northern* polarity to the denomination of magnetism induced or attracted by the earth's magnetism of the *same* name, it is difficult altogether to avoid the incon-

gruity of expression. Bearing in mind, however, the fact of the existing inappropriateness in *this one case* of calling by the same name, instead of by converse denominations, the inducing and the induced polarities, we shall have less inconvenience in description, in all other cases, of using the popular names of north and south poles of the magnet, rather than (unless by special occasion) those of "marked end," and "unmarked end;" for in every other instance, the grand elementary laws of magnetism, both as to induction and attraction, will be consistently indicated by the designation of northern and southern polarity, viz. the law under which either polarity, acting inductively, developes that of contrary name, and the law under which the two different polarities are reciprocally attractive of each other, whilst those of the same denomination are repellant.

[3. *Exp.*]—The *evanescent* character of the induced magnetism in connection with the general phenomena, will be further shown by placing one end (say the knob end) of the poker, held horizontally, against the edge of the table, with the compass about three inches within. Raising the point with one hand, whilst the knob is kept steady against the table with the other hand (like a ball moving in a socket), the north pole of the needle will gradually recede, till the poker becomes

vertical (as represented in the figure), and then lowering the point, the north pole will gradually approach the knob, till the poker becomes again

Fig. 1.



vertical in the direction opposite to its former position; thus showing that the knob had obtained northern polarity when the bar was vertical with

the knob downward, and southern polarity with the knob upward.

[4. *Exp.*]—If, whilst the knob is held in the ball and socket fashion, the point of the poker be alternately raised and depressed, in a regular succession of changes, the needle will be made to oscillate; and if the changes are made with a due regard to the period of the needle's natural oscillations, it will be made to go round and round, unceasingly, so long as these movements of the poker are consistently continued.

This alternation of polarities in the knob from southern to northern, by the inversion, in position, of the poker, leads, on the principles of inductive science, to the inevitable inference that there must be some *intermediate* position, in which neither the one nor the other polarity would be dominant; or, in other words, where the iron would be found neutral.

[5. *Exp.*]—This inference is conclusively exhibited, by raising the point of the poker, whilst held by the knob as before, gradually upward (commencing with a vertical position, point down), when the quantity of the magnetic action is found to diminish as the bar approaches the horizontal; but, in a different degree, according as it is raised in an east and west plane, vertical

from the dotted line E W, or in the meridional plane, at right angles to the other. In the former progress, the bar, if entirely free from inherent magnetism, will become neutral in the *horizontal* position; but, in the latter (if traversed northward of the compass), it will pass *beyond* the horizontal about the eighteenth part of a circle, or rather more than 20°, before the same neutral effect takes place.

These facts, which were elicited by original investigations made betwixt the years 1815 and 1819, yield the conclusion arrived at by an independent and admirable series of experiments, carried on at, or about, the latter period, by Mr. Barlow, that the influence by which the magnetism of iron bodies is elicited thus spontaneously, acts in a direction, not perpendicular to the earth's surface, like gravitation, but in a direction inclined in the same degree as that of the earth's *magnetic* action.* Hence it follows that the plane of neutrality, or *no-attraction*, lies at right angles to the direction of the dipping-needle, being inclined to the horizontal, in the

* The original paper, embodying the portion of the investigations relating to the sources of the deviation of the compass on ship-board, was drawn up, mainly, during a voyage to the Greenland whale-fishery, in the year 1817, and communicated in the form in which it appears in the Philosophical Transactions, to Sir Joseph Banks, Nov. 3rd, 1818.

southern part of England, at an angle of from 19° to 20°.

The strict and rigid correspondence of the inclination of the neutral plane with the complement of the dip, is admirably exhibited by means of an original instrument, hereafter described, constructed in the year 1819, for the measurement of minute magnetic alterations relating to angles of position, also for the determination of the plane of no-attraction, and for deducing, from thence, the *inclination* of the earth's magnetic axis.*

The condition of neutrality in the experiments above described, with the poker held in the plane of the magnetical equator, is obviously the necessary consequence of the earth's magnetisms acting equally on the whole length of the bar. For whilst, with one end depressed, in respect of the plane of the earth's magnetic equator, a northern polarity was induced on the depressed end; with neither end depressed, a northern polarity, if any, must be induced entirely along the lower *surface* of the bar, but so, as when thus closely associated with the converse polarity on the upper surface, as to present a neutral condition in its action on the compass.

* Account of the Arctic Regions, vol. ii. p. 540.

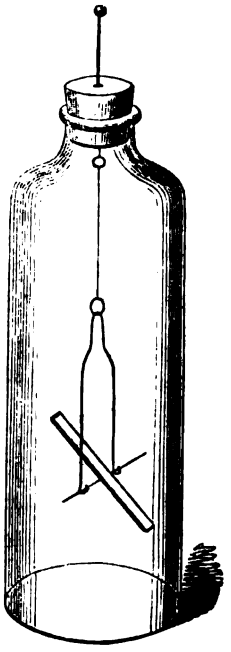
SECT. IV.—*The Direction of the Earth's Magnetic Action illustrated.*

FOR the due illustration of the *true direction* of the earth's magnetic action and its effects, we are naturally led to further elementary considerations on the means by which this direction is indicated and determined. The suspending and balancing horizontally of a needle, or a piece of steel wire, by a thread, a hair, or a few fibres of silk, and observing the new and peculiar position it assumes after being magnetized, is the familiar mode of illustrating the absolute *direction* of the influencing forces in the earth. In this case, whilst the direction in the plane of the magnetic meridian, as in the common magnetic needle, is taken, by the suspended wire, we have associated therewith an inclination or dip, with reference to the horizontal plane, in an angle, approximate, in this country, to about 70°.

As, however, the point of suspension of such a needle on a loop or hitch of thread, will not accord with the centre of gravity, the inclination taken by it when magnetized, will give no correct indication of the true magnetic direction. For, if previous to being magnetized, it be correctly balanced, the quantity of inclination will commonly be very much less than that exhibited by the truly-acting *dipping-needle.*

[6. *Magnetic Direction Needle.*]—In order to render the experiment completely effective, the bottle apparatus, which we here figure, and proceed to describe, was constructed.

Fig. 2.



Two pieces of watch-spring, two inches in length each, were broken off with square ends, by means of a pair of small pliers. After the pieces had been alternately heated, very slightly, in the flame of a candle, they were coated, on the concave side, with the wax of a common taper. The object of this was to give some adhesiveness to the two plates when combined, to yield space for the introduction of an axis, and to give sufficient fixedness of position to the axis when duly adjusted. Placing, then, the two plates with their concave and waxed sides together, they were wound round, from end to end, nearly, with fine thread, in even and closely continuous turns. Betwixt the steel plates thus combined, and midway from each extremity, a fine sewing needle was inserted, transversely, or at right angles, to the length of the plates, as an axis.

A piece of brass wire, of the thicker kind employed for the piano-forte, about four inches in length, was bent into a loop or staple form, and the two ends turned into small open eyes, as a stirrup or support for the magnetic direction-needle. The two ends, or eyes, of the looped wire, when brought together within about half-an-inch, were adapted (being on the same level when the suspension-wire was hung by the bend of the loop) for the reception of the axis of the needle, and for allowing it to turn thereon, without interruption to its free motion.

The watch-spring needle being now suspended on the wire support, was adjusted, as to the equalizing of the weight of its two arms, by a minute quantity of sealing-wax; and, as to the adaptation of the centre of gravity of the plates to the axis, by the accurate straightening of the plates, which, from their mode of combination, could be easily done by the fingers.

These adjustments being so far effected as to leave little or no tendency in the needle to assume any particular position, it was then magnetized, when the northern pole became inclined, exactly, as far as could be determined by the unaided eye, to the angle of the dip. Reversing the polarity, in order to test the accuracy of the adjustments, the result was found to be similar, and, consequently, the action satisfactory.

To complete the instrument, the supporting wire, or stirrup, was passed through a small ring of brass, attached to a few fibres of raw silk, the other ends of the silk being hung from a wire passing through the centre of the cork of a wide-mouthed phial; and, finally, the little apparatus, whilst suspended from the detached cork being let down into the phial, the needle became free to assume the precise direction of the earth's magnetic force, uninfluenced by currents of air, on the cork being placed in its proper position.

The action of the little instrument was quite beautiful; for all the effects, as far as illustration requires, of the most costly dipping-needle, and indeed more, were exhibited by an apparatus, constructed out of materials everywhere to be had, at the expense only of about *threepence* in materials, and of little more than *an hour* in time!

In the adjustment of this *Magnetic Direction-Needle* (as it may be characteristically denominated), so as to enable it to take a position truly in the vertical plane of the magnetic meridian, attention needs to be given to any twist that may happen to be in the suspension-silk. This is easily determined and corrected by suspending a weight from the same fibres equivalent to that of the dipping-needle, previous to placing it in its looped stirrup. The same effect, indeed, may be pretty well obtained, by placing the suspended

needle in a line with the needle of a compass, at some little distance, by which any deviation, from torsion, can be detected; and, in case of deviation out of the magnetic meridian, adjustment can be effected by turning the wire, to which the suspension-silk is hooked, until the proper meridional position is taken by the needle.

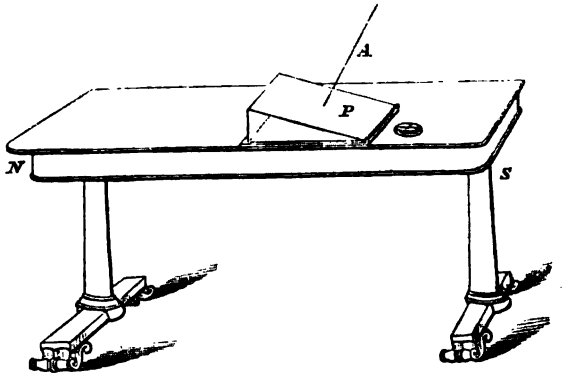
SECT. V.—*The Plane of Neutrality or No-Attraction illustrated.*

THE *direction* of the earth's greatest inductive influence is found, as indicated by experiments of the nature of No. 2, p. 14, to be that which a magnetic needle, equally poised, and free to adjust itself in parallelism with the earth's polarity, would assume; that is, the position of the magnetic direction-needle, just described. And the *plane of neutrality* is consistently found to be a plane to which the axial position, or that taken by the dipping-needle, is perpendicular.

As no inconsiderable body of the Investigations described in this volume have relation to the action of terrestrial magnetism, it may be here convenient to give a practical illustration, or representation, of the position of an oblique plane, in parallelism with which the earth's influence, as to its action on iron bars, will be neutral, whatever may be the point of the compass to which the bars may be directed.

[7. *Illustration.*]—The *plane of neutrality*, or no-attraction, with the direction of the earth's magnetic axis, may be thus familiarly represented.

Fig. 3.



On the surface of a table, as high as the length of any bars to be operated with, place a thin quarto or folio volume:—I prefer a music-book, as particularly convenient both in size and form, for the purpose designed. Adjusting the table, in the first place, so that (if a square-sided table is used) its sides shall correspond in direction with the cardinal points of the compass, the side N S, as in the figure, being north and south; then place the music-book, with its *opening* edge towards the north, so that one of the ends shall be parallel to, or coincident with, either the eastern or western side of the table. Immediately in contact with the back or hinge of the book, and resting on the table, place a small compass,

which will serve both for the adjustment of the equatorial magnetic plane, and for experiments in connection therewith. Cut two small sticks, with sharp ends, like common butcher's skewers, (or two pieces of wire) of the length of 3·4 inches, and, raising the upper board of the volume, place them one at each corner, close by the edge, or so as to be ten inches distant from the hinge of the book, and in this position to hold up the board. Thus arranged, the hinge and front edges of the volume will lie horizontally in an east and west (magnetic) direction; and the superficial plane P, will lie at an inclination of about twenty degrees with the horizontal level, rising towards the north, so as to represent the *plane* of the magnetic neutrality, or no-attraction. In parallelism with this plane, therefore, or laid flat upon it in any direction whatever, as to the points of the compass, the iron-bar, if properly demagnetized, will equally exhibit a condition of neutrality. This is *the plane of the magnetic equator.*

A ruler, or other straight rod or bar A, placed perpendicularly on the plane above described, will be parallel to the resultant of the earth's magnetic forces in England, thus forming an angle of about 70° with the horizon in the plane of the magnetic meridian—the upper end inclining towards the south, the lower end *dip-*

ping towards the north; that is, the rod or bar will be in the position of the magnetic axis, or dipping-needle.*

Sect. VI.—*On the General Action of Terrestrial Magnetism in regard to position.*

We add here, also, some further illustrations, experimentally exhibited, of the general character and effects of the magnetical influence exerted by terrestrial induction. These illustrations are designed more particularly to show the relation of the effects produced to *position;* that is, to the position, relatively considered, of the mass of iron, magnetized by the earth, and the direction of the earth's magnetism.

[8. *Exp.*]—Of the mode of action of terrestrial magnetism on an easily magnetizable substance, we may take this simple illustration:—

Let M, fig. 4, be a straight bar-magnet placed, in this case, with its north pole downward. Let I be a small bar of iron, or bit of iron wire, held at a short distance above it, and in the line of its longer axis. Magnetism will be induced in the iron, with poles in the same order as those of the

* The inclination of the needle in England varies from about 69° to 71°; but that here and elsewhere assumed, is sufficiently near for ordinary experiments.

master-magnet, that is, a north below, induced by the south pole of the magnet, and a south, produced consequentially, above. If 1 be inverted, the polarities will be immediately reversed; and if placed directly across the axial line of the magnet as at *i*, fig. 5,—the position corresponding, illustratively, with the plane of the magnetic equator,—the polarities will be mainly neutralized, because the same denomination of polarity (if the bar or wire be sufficiently thin and short), will be acting on its whole length.

Fig. 4.

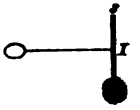
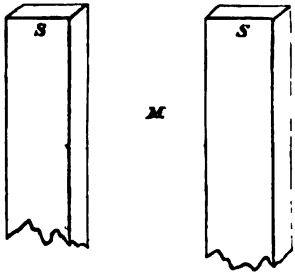


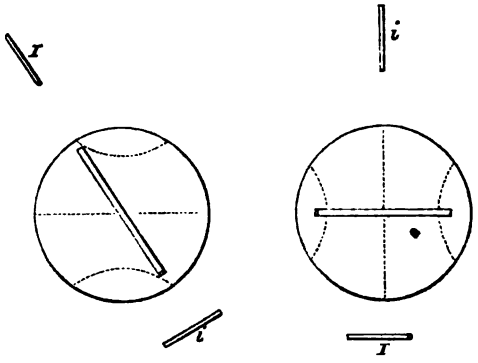
Fig. 5.



[9. *Illustration.*]—Let, now, the magnet be supposed to be inclosed in a sphere, and it will represent, so far as is needful for our purpose of illustration, the condition of a bar, or other mass of iron, as affected, under different positions, relatively to that of the dipping-needle, by the earth's magnetism.

Thus 1, fig. 6, will represent, very fairly, the magnetic condition of an iron bar, in our own

Fig. 6. Fig. 7.



magnetic latitude, when held in the position of the earth's magnetic axis, by the development of northern polarity below, and southern above; whilst *i* will represent (though less perfectly) the neutral condition of the bar as placed horizontally in an east and west direction, in respect to the earth's surface. Again, I, fig. 7, will represent the condition of an iron bar in an equatorial magnetic region, becoming most strongly magnetical, when in the horizontal position, and neutral, when, as at *i*, placed upright.

The magnetisms developed, in these cases, where a powerful bar-magnet is employed, will be sufficient, in the position I, not only vigorously to give direction to the needle of a compass, but to suspend small keys, nails, or bits of iron. The neutral position, however, is less perfectly illustrated because of the necessarily too great

dimensions of the piece of iron, which ought to be, for the proper comparison, indefinitely small. If, however, iron-filings be used for showing the effect of induced magnetism, and a short piece of iron wire be substituted for the bar 1, the illustration may be effected quite satisfactorily. In my own experiments, under this modification, I employed a bar-magnet of 15 inches in length and 1·5 inches in breadth, for the inducing agent, and a bit of iron wire, an inch in length and one-tenth diameter, as the recipient. The bit of iron, supported at the middle by a piece of brass wire, as represented in fig. 4, was held in the position 1, at the distance of three inches from the upper pole of the magnet, when a brush of near the size of a French bean was taken up by it from the surface of a small card; but when the wire was placed horizontally across the poles, at the same distance, as shown at *i*, fig. 5, the filings almost entirely dropped off. In some cases, indeed, the wire retained none of the filings when, supported on the card, a quantity of them was put into contact; in others, a very few minute particles might adhere by virtue, probably, of the magnetic condition induced in the filings themselves acting on the iron wire, and so becoming attracted.

CHAPTER II.

ON THE ACTION OF TERRESTRIAL MAGNETISM ON IRON AND STEEL OF DIFFERENT KINDS, AND ON IRON AND STEEL OF VARIOUS PROPORTIONS AS TO SURFACE AND MASS.

SECT. I.—*Leading Characteristics of Terrestrial Induction.*

THE general action of terrestrial magnetism on ferruginous bodies, is to develop in them magnetical qualities, in degrees of energy varying with the quality, size, form, etc. of each mass, but uniform in its effects in regard to the polarities developed, and the adjustment of the axial and equatorial positions.

In regularly formed or straight bars of iron or steel, being of uniform quality and temper, and held in an upright position, or in any direction proximate to that of the magnetic axis, the upper half, where there is no actual magnetism pre-existing, will, as we have already shown, be always found to have southern polarity, and the lower half northern, whilst, exactly in the middle of the bar, will be found a neutral place, having no magnetic action whatever.

In other regularly formed masses, such as

spheres, cubes, parallelopipedons, ovoids, cylinders, prisms, etc., an oblique plane passing through the centre of gravity of the mass, corresponding, in parallelism, with the plane of the magnetic equator, will generally define, throughout the circuit of each separate mass, the neutral position,—the portions above this neutral plane having southern polarity, and those below northern polarity.

This fact, in the case of spherically-formed masses,—such as iron shot, shells, and spheres of sheet-iron,—has been so amply demonstrated by Professor Barlow; and the laws of attraction, or action thereof, on the needle of a compass, in every variety of relative position betwixt the iron and the compass, have been so thoroughly and scientifically developed, as to leave nothing, apparently, to be sought by other investigators.

In regard, however, to the *degrees of energy* in the magnetism developed by the earth's action in the various kinds of ferruginous bodies, generally, my personal investigations have led to the conclusion, that the differences of such energy are far greater than seem to have been heretofore understood. And in regard to prevalently-received conclusions, with respect to the dominancy of surface, over mass, on the capacity for terrestrially-induced magnetism, these investigations, as I was led to anticipate, have yielded

results, which, to me appear, to be totally different.

Among the large variety of enquiries, in respect to this branch of magnetical phenomena, to which my investigations have extended, I select, as of chief novelty and importance, those described in the following sections.

Sect. II. — *General Arrangements and Plan adopted for the Investigation of the Inductive Action of Terrestrial Magnetism.*

In some important particulars, the present investigations on this subject, and especially on the relation of *surface* and *mass*, as affecting the capacity of iron and steel for terrestrially-induced magnetism, differed materially from the mode of operation adopted by former experimenters. The most important difference, however, consisted in the employment, in the first instance, of numerous thin plates of iron and steel, instead of single separate masses, in various series, as to the numbers combined, and in different conditions, as to the degrees of hardness, of the various qualities of metal subjected to experiment. For, in observing the varieties of magnetic energy elicited under such arrangements, there appeared to be a fair prospect (as to which I was by no means disappointed), not only of obtaining interesting

information on the ratios of power in the different series; but, by comparing such ratios with the simple results in thicker plates or bars, individually tried, of gaining satisfactory results on one principal question, as to the relative effects of *surface* and *mass*.

For these investigations, I procured, at the commencement of my proceedings, a considerable number of thin plates of rolled iron and of cast steel, the former being cut out of thin sheet iron, and the latter being plates, in their *hard* state, as in process of preparation for busks. A *few* iron bars (subsequently increased in number and variety) of uniform length, but of different weights and form, as to the grooves in which they had been rolled, were also provided, —the whole being ordered to be in the crude or unannealed state.

Experiments, it may be added, were made with plates of iron of two different sizes; but, as the results were correspondent, it will be necessary only to describe those obtained with the series expressly cut out to suit the dimensions of the hard-steel plates which I happened to have in hand.

Of the sheet-iron plates, in the crude state, as obtained from the rollers, a dozen of the size of the busk-plates were provided for combination. They were about 15 inches in length, 1·5 in

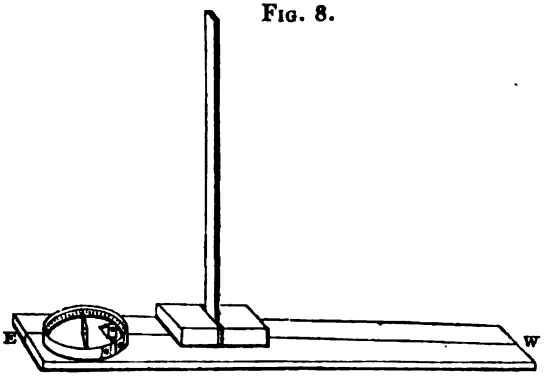
breadth, and ·03 in thickness; weighing, on an average, 1246 grains. The steel plates, which were as hard and as brittle as glass, were of the same dimensions, except slightly differing in thickness, weighing about 1078 grains each.

As the relation of their magnetic powers, under the simple action of the earth, could as well be determined by a *vertical* position, as by that of the direction of the axis of terrestrial magnetism, I adopted that position as being more conveniently investigated.

The test of magnetic energy was a Kator's compass, placed on the *deviation-board*, described in vol. i. page 31; the iron plates, etc., being supported in an upright position, between two square-sided pieces of lead, at the uniform distance of *six inches* from the centre of the compass. The lower ends of the plates, in this case, rested upon the surface of the deviation-board, which was about half-an-inch below the level of the compass needle,—a position deemed preferable to that of the exact level, because of its bringing the centre or focus of attraction, in the lower end of the plates, nearer to a correspondence with the horizontal plane in which the magnetic needle traversed. The general arrangements for these experiments are represented in the annexed figure.

The deviation-board, E W, being placed in the

Fig. 8.



magnetic east and west, and so as to bring the compass needle into exact conformity with the north and south line of the instrument,—the prior condition of the plates, as to any existing magnetism, could be exactly determined by first placing them flat on the central line of the board, where, being in the plane of the magnetic equator, they must be free from any determinate influence from the earth.

Sect. III.—*On the relative Powers, inductively developed by the Earth's Magnetic Action, of thin Plates of Iron in various combinations, and of the comparative Powers of thicker masses of Iron, singly.*

Several series of experiments, under these arrangements, were made with the *iron plates*, both in their crude state, and after they had been annealed pretty uniformly throughout their

length at a low red heat. And, connected with these series, was the trial, from time to time, of the magnetic powers of several round bars, and flat bars or thick plates, designed for comparing the effects of surface and of mass, as well as of fasciculæ of plates and equal solid bars.

The plates, on every application to the deviation-board being carefully neutralized, were tried first separately, and then in combination in various numbers, and in combinations of different sets of plates of like numbers, as to their action on the compass, respectively, in the vertical position. Three readings of the compass, on presenting each end of the bar or plates, were made for the registration of a single result. 1. As to the existence of any slight degree of magnetism in the equatorial position; 2. As to the deflecting power in the vertical position; 3. As to the altered state of polarity *after* the subjection to a vertical position. The difference of 1 and 2 was noted as the simple effect of induced magnetism; and the difference of 1 and 3, as the quantity of "*retentive magnetism*," (a denominative term hereafter more particularly elucidated and explained,) gained by position. The opposite end of the plates being tried in a similar manner, the mean differences of 1 and 2 were registered as results.

The magnetic condition of the various series

of plates and bars, in their crude state, was thus repeatedly tried, till results of a very satisfactory nature and relation were obtained. But being by no means disposed to believe that a like measure of magnetic susceptibility, only, would pertain to iron in a different state as to consolidation or hardness,—I subjected the greater part of the plates, which, in their crude state, had previously had their magnetic developments tested, to the action of a low red heat, as equally as possible throughout, and the larger bars to a still more effective annealing.

TABLE I.—Magnetical Powers, terrestrially induced, of Plates and Bars of malleable Iron, in their crude state and after being annealed. Distance from the Compass six inches.

No. of Exp.	Description of the Iron.	Weight.	Crude Iron.		Annealed Iron.	
			Magnetism vertically acquired.			
			Mean Deviation	Tangent.	Mean Deviation	Tangent.
i.	ii.	iii.	iv.	v.	vi.	vii.
		Grains	° ′		° ′	
I	1 Plate .	1,246	1·17	224	4·4	711
II	2 „ .	2,493	2·17	399	5·48	1016
III	3 „ .	3,740	3·20	582	7·10	1257
IV	4 „ .	4,987	4·30	787	9·5	1593
V	6 „ .	7,480	5·27	954	10·31	1856
VI	8 .	9,974	6·49	1195	11·44	2077
VII	10 „ .	12,467	7·52	1382	12·25	2202
VIII	12 „ .	14,960	9·0	1584	—	—
IX	Thick plate	3,830	4·42	822	7·37	1337
X	Flat bar .	11,400	11·57	2116	12·15	2171
XI	Flat bar .	15,000	12·21	2189	12·55	2293
XII	Round bar .	2,280	2·37	457	4·25	772
XIII	Round bar .	5,400	7·15	1272	7·38	1340

The mean results, as derived from a selection from the *best* series of experiments,—as they improved in satisfactoriness by the adoption of various delicate matters of care and consideration in the conducting of the manipulations suggested by increasing experience,—are exhibited in the preceding table.

Considerable as it was assumed the effect of *annealing* might probably be, in increasing the capacity of iron for receiving magnetism from the earth, it proved, on trial, much greater than had been anticipated. In the case of a single plate, No. 1, we find an advance, by annealing, from a deviating influence of 1° 17′ to 4° 4′, indicating a gain of power of nearly three and a half to one;—the single annealed plate being found to have a force of action on the compass nearly equal to the action of four plates in combination, in the state in which the sheet iron came from the rollers. This *proportion* of superiority, indeed, was not maintained in the combination of larger numbers, for reasons, sufficiently appreciable, which we shall just now offer.

Comparing the magnetic influence, developed by the vertical position, in the *thicker* plates and bars, in single masses, with that elicited in the *thin* plates, combined in like masses, but presenting much larger measures of surface,—we find a very different result from that at which other

experimenters seem to have arrived. For whilst some have been led to infer that the recipient magnetism of iron, terrestrially induced, has mainly relation to the *surface*, with little or no regard (except in extreme cases) to the mass,—we find the relation, in *these special experiments*, in scarcely any degree referable to the surface, but, mainly and essentially, to the mass.

The thick plate, No. IX. for example, about 15 inches long, one inch broad, and ·125 inch thick, weighing 3830 grains, had, when annealed, a deviating energy, in an upright position, of 7° 37′, whilst three thin plates in combination, No. III. of 3740 grains, had but a power of 7° 10′. But whilst these powers follow so extremely near the proportions of the *masses* of the iron compared,—they are found to be most remote from the proportions of surface,—the quantity of surface being about four times greater in the thin plates than in the thick one.

Comparing the flat bar, No. X., which was an inch broad, and a quarter-inch thick, and had only 46 inches of surface, with ten plates, in combination, No. VII., whose weight was about a twelfth part greater, but had a quantity of surface ten times larger, we find a corresponding result;—the deviations being respectively 12° 15′, and 12° 25′, or in extremely near relation to the mass.

The relation to mass, though not in each case quite so close in bars XI, XII, and XIII, yet obviously approximates the same rule.

The comparison, however, needs to be made in the *annealed* state of the plates and bars, and not in the state in which they came to my hands, because of the extreme uncertainty of the original condition, as to relative degrees of hardness or compression in texture. For comparing the powers of bars X, XI, and XIII (as shown in columns iv and vi), which were ordered to be in their crude state as they came from the rollers of the iron-works where they were fabricated,—we find it indicated, I would say demonstrably, that each of these bars must have been heated pretty nearly up to the annealing state (probably for convenience in being cut into the required lengths), when in the hands of the smith.

SECT. IV.—*On the Relation of the Magnetic Energy in malleable Iron, terrestrially induced, to surface and mass.*

CONCLUSIVELY as I conceive this enquiry to have been determined in respect to elongated solid masses and combinations of plates, such as those which were employed in the experiments described in the preceding section, yet, because of the high scientific character of investigators who

have come to conclusions essentially different, the subject seemed to claim some further and more special consideration. The analogies, indeed, betwixt the experiments above recorded and those with which they have been compared, may not be considered, perhaps, sufficiently accordant to justify a diverse conclusion; for the investigations referred to related to the comparative capacity for inductive magnetism of solid and hollow masses of iron, and mine to solid masses and combinations, in compact superposition, of thin plates.

In order, therefore, to justify the inference of there being some mistake in the conclusions drawn from the researches of other experimentalists, and at the same time to invest our investigations with the enlarged characteristics requisite for deducing from them results of the nature of general laws,—there was an obvious call for an extension of our experiments into more strict analogy with those made, with a similar object of enquiry, by the late Captain Kator, and a portion of those by Professor Barlow. For no inconsiderable measure of my own experience in the investigation of magnetical phenomena had gone to show the prevalent limited applicability of particular cases for, and consequently the risk of applying them to, the determination of general laws. The Results of chapter v. part ii.,

strikingly show the errors into which both investigating and practical magneticians have fallen, in assuming, as often has been done, that what they had realised, as to the power of magnets of a *particular* nature, quality, form, or proportions, would necessarily apply to other cases, much less to magnets generally.

It does not fall within my province or means to touch the case of the magnetism of *spherically-formed* iron, which has been so elaborately and admirably investigated by Professor Barlow, except as the general law, in respect to the influence of surface over mass, to which these investigations appear to lead.

The question of the relation of the magnetisms, terrestrially developed, in *solid bars*, and in *hollow vessels or tubes* of iron of similar lengths, as influenced by surface and weight, was one which, whilst sufficiently appropriate to apply to the circumstance of the discrepancies in the conclusions we have referred to, became, under the means at command, of comparative easy investigation.

On this enquiry, as to whether the energy of induced magnetism in iron bodies of similar lengths, or of like general dimensions, be in the ratio of the surfaces, or of the masses, or relatively to both? several sets of experiments were suggested by the means in my hands. Of these, a portion only will need particular description.

1.—For the first set of experiments, some of the thin iron plates described in section iii., being cast into a new form of arrangement, were employed.

Three of these plates, with one of them cut into half-breadth slips, were combined into a hollow parallelopiped of about 15 inches in length, by 1·5 inches in breadth, and 0·4 inch in thickness,—corresponding, very nearly, in external dimensions and form, with the larger compact combination (No. VIII. Table I.) of iron plates.

The comparative magnetical powers, terrestrially induced, of these plates thus combined as a tube, and the same combined in a compact mass, were first determined, — the deflecting power, when hollow, being found, on the average of several trials, to be 8° 2′, and, when bound compactly together, 7° 10′. This result indicated no other difference than what was obviously due to the favourable effect of attenuation of the magnetic forces in the plates by distribution; a general fact which, in part ii., chaps. ii. and v., was so extensively elucidated in respect to permanently magnetic steel plates. And comparing the magnetic force, represented by 8° 2′ deviation, of this hollow parallelopiped, of the weight of 3740 grains, with that of the solid plate IX. of 3830 grains, indicated by a deviation of 7° 37′, we find a very satisfactory agreement, for this

special case, in favour of the law of mass, rather than of surface.

2.—The next set of experiments was made with a tinned-iron vessel, in shape a rectangular prism, of 3·5 inches width, each side; my object being to compare its inductively received magnetism, with that of a combination of iron plates of somewhat like *length* and *mass*. The tinned vessel weighed about 7650 grains, and, allowing for the probable weight of the coating of tin, might comprise about 6700 or, say, 7000 grains weight of iron.

In trying the deviating powers of this vessel, so as to afford a proper case for comparison with the powers of compact or solid masses of iron, the question of the adjustment of the *distance* from the compass, so that the relative action of the magnetisms of the two forms of iron substances to be compared might act equably, became a subject of important previous consideration. For whilst a distance of six inches, as in the case of a thin solid plate, betwixt the centre of the compass and the *nearer* surface or side of the tin case, would be obviously too remote,—a distance of six inches betwixt the *centre* of the compass and that of the case would, as is easy to be shown, be too near for a just comparison. A thin bar, or combination of plates, where the flat

side is presented to the compass, will have its magnetic forces acting on the needle, so near to the centre of the mass, in thickness, that, in measuring the distance from this centre, no account, practically, is needful to be taken of an inappreciable error. But it is far otherwise where an iron body of very considerable thickness is tested, and the more so when the distance from the compass is small.

The instance before us may fitly serve for illustrating the principle. Considering only the action of the *lower* half of the vessel, which, from its comparative nearness, exerts a dominant influence on the needle, we may regard the magnetisms of the entire surface as concentrated in two foci of attraction, situated a little within, or, indeed, almost upon two sides – the one nearest to, and the other most remote from, the compass. Both these foci, being of the same denomination of magnetism, will act in the same direction on the compass needle, serving to aid the deflection, mutually, with a force inversely as the squares of their respective distances. But the sum of their forces will be greater than the effect of the like forces, if supposed to be concentrated in one focus in the *middle* of the lower end of the vessel; and, consequently, if the tinned vessel were placed with the central point of its base, at the distance at which the iron bars were placed,

its action on the compass would be disproportionate.

With a view, therefore, to a just comparison of the magnetical forces of bodies differing so greatly in width or diameter as the tinned iron vessel here employed, and the compact iron bars or bundle of plates,—the adjustment of distance, with reference to the compass, should, it is obvious, be made by measurements, not betwixt the middle or centre of the bodies, respectively, but betwixt the *general focus* of magnetic action of each body and the centre of the compass.

The inaccordance of measurements of distance taken from the centres of magnetical bodies of very different widths, with the common centres or foci of their magnetic action on the compass needle, may be more familiarly represented by assuming a somewhat extreme position of nearness. Suppose the case of a *long* tube of iron, (the *length* of the tube being designed to reduce the antagonistic action of the upper polarity, so as to render it unimportant in the enquiry,) of two inches square, placed upright at the distance of two inches, measured from its centre, from an indefinitely *small* compass needle.* The nearest

* An indefinitely small compass-needle is here assumed for illustration, in order to get rid of the additional embarrassment arising out of the effect of the same principles on a compass, when in a state of deflection, where the needle is of considerable length.—*See* chap. iii. part i.

side, or the nearest focus of magnetic action, would then be one inch, and the most remote side or focus three inches from the compass. Their united action, consequently, would be represented by the sum of the squares of these distances, inversely, or, fractionally and directly, by the sum of the reciprocals of $1^2 + 9^2$, that is, $\frac{1}{1} + \frac{1}{9} = \frac{10}{9} = 1{\cdot}111+$. But the force of the entire magnetisms, if concentrated in one point at the mean distance of two inches (the central place assumed to be occupied by the tube and bar to be compared) would be only as the reciprocals of two equal squares of such distance, $2^2 + 2^2$, or $\frac{1}{4} + \frac{1}{4} = \frac{1}{2} = {\cdot}5$.

Now here, we find, that a comparison being made betwixt a tube so situated, with its centre two inches from the compass, and a thin plate or bar at the same distance, would give an apparent magnetic power in the tube of more than *double* the reality, the excess of force being in the proportion in which the sum of the reciprocals of 1^2 and 3^2 (expressed fractionally) exceeds the double of the reciprocal of the square of the central distance, or $2^2 + 2^2$, similarly expressed. Hence, for a proper comparison of the wide tubular iron with solid thin bars, at the distance, in respect to the latter, of two inches from the compass, the tubular vessel must be removed further off, or until the general resultant of its

entire magnetic action shall be reduced to the quantity of ·5, instead of 1·111+; or what would be the same thing, the solid bar must be removed nearer to the compass, until its quantity of action, with respect to distance, become equivalent to that of the tubular mass, or 1·111+. Calculating the positions for this latter adjustment, we find, as to the particular case employed now for illustration, that, at the distance of about 1·34 inches from the compass, the solid bar would be in a position for a just comparison with the tubular iron at the distance of two inches, measured from its centre, or one inch measured from the side nearest to the compass.

In the experiments, therefore, with the wide vessel of tinned iron, now particularly referred to, the adjustment of the distance from the compass, so that its general focus of magnetic action should correspond with that of a solid bar at the distance of six inches, was a matter of special attention. And, on the principles just elucidated, it was found, that, for the particular case, a distance of 6·5 inches, measured from the centre of the base, when standing upright, of the tinned-iron vessel, would correspond (sufficiently near for all practical purposes) with a distance of six inches measured from the centre of the solid bar, or compact combination of iron plates, similarly

supported, so that the general resultants of their respective magnetisms might act equably, with respect to distance, on the needle.

Thus adjusted, as to distance, respectively, a numerous set of experiments was made with the hollow vessel, and with the solid or compact iron. The first object was to free the vessel from accidentally-acquired magnetism, which was satisfactorily effected by a few taps of a bit of wood, on each of it sides in succession, whilst it was held, nearly horizontally, in a predetermined favourable position. Its magnetic action on the needle was then repeatedly tried, with each of its sides successively presented to the compass, when standing upright on the surface of the deviation-board, in the line of the west point of the compass, and with its base nearly on the level in which the needle traverses. The mean deflection of the needle thus produced, was found to amount to 8° 30′.

The plates of rolled iron, used in former experiments, served satisfactorily, because of their ascertained correspondence of magnetic action with that of solid bars, for the purpose of the present comparison. And a combination of six of these, weighing altogether 7480 grains, served remarkably well in respect to mass, differing scarcely 500 grains from the estimated quantity of iron in the tinned vessel. These six plates,

compactly bound together, had a deviating power at six inches distance from the compass, as shown in table I., *unannealed*, of 5° 27′, and, after being *annealed*, of 10° 31′. The power of the tinned-iron vessel, which must have received a measure of annealing in the tinning process, was, we perceive, intermediate betwixt the powers of the iron plates in their two conditions. The relation, therefore, in magnetical qualities, is here again obviously shown to be in striking consistency with *the mass*.

3.—With a cylindrical case of tinned-iron, a further means of comparing surface and mass, in their relation to the recipient magnetic powers of iron, was satisfactorily afforded. This case was 18 inches in length by 2·5 inches in diameter. Its weight of iron, deducting 530 grains for the tinned surface, was estimated at 3800 grains. Its magnetic powers, when neutralized and adjusted to the distance proper for the general centre of magnetic action, were compared with those of two plates of thin sheet-iron of the same length, weighing 4320 grains, and also a single thicker plate of 4600 grains. Here, where the proportions of *surface* in the tinned case and iron plates, differed in the ratios of about 3 to 1 and 7 to 1, there was such near agreement in the magnetic powers, as fully to

support the conclusions derived from the previous experiments.

4.—Another set of experiments, adapted for a further comparison of the magnetic powers of iron of different thicknesses, we here record, in which the relation of the plane whereon the upright iron was rested, to the horizontal plane in which the compass-needle traversed, was repeatedly and extensively varied.

Two plates and a thin bar of iron, about fifteen inches in length each, and all of them annealed, were selected for the comparison. They were taken from the series of table I., numbered I, IX and X, being of the weights, respectively, of 1246, 3830, and 11,400 grains.

The compass, in this set of experiments, was elevated nine inches above the surface of the deviation-board, so that the plates, whilst placed in an upright position, might be so depressed as to have their action on the compass tried whilst their middle or centre was varied in their relative position, as to level, for more than one-half of their length. When the lower ends of the plates rested on the deviation-board, the centre, or middle, fell 1·1 inches below the level of the compass; and when raised to the level of the platform which sustained the compass, the centre was seven inches above the needle. Trial was

made of seven different levels, on and within the range of these extremes,—in each case the three plates being successively placed with their flat sides opposite to the compass, in the line of the magnetic west from its centre, and at the distance of six inches as before. At the commencement, the magnetism of the plates was carefully neutralized, and the register of the deviating action of each was made on the mean of the two ends, on their being placed alternately upward and downward. The general results were as follow:

TABLE II.—Magnetical Powers, terrestrially induced, of three Plates or Bars of malleable Iron, whilst placed in a vertical position, at the distance of six inches from the Compass, and supported at various levels, with respect to the level of the Compass.

Centre of Bar above or below the Needle.		Plate I. 1246 Grains.	Plate IX. 3830 Grains.	Bar X. 11,400 Grains.
		Mean Deviation.	Mean Deviation.	Mean Deviation.
Inches.		° ′	° ′	° ′
7·0	*above*	3·38 E	7·37 E	12·15 E
5·7	„	2·56	6·55	12·12
4·4	„	2·30	5·52	9·45
2·4	„	1·0	3·20	5·15
0·9	„	0·15 W	1·7	1·10
0·1	*below*	0·20	0·31 W	1·45 W
2·1	„	1·22	2·10	5·20

Here again we find the law of mass, rather than of surface, as obvious as before. In the

equatorial position of the plates, that is, where the *centre* of the plates was on the same level, or nearly the same, as that of the compass-needle, the law becomes necessarily unobservable, because of the antagonistic forces, above and below the plane of the compass-needle, acting equally, and so destroying each other. But beyond the distance of an inch from the equatorial position, the effect of mass becomes apparent, increasing in conspicuousness according as the distance from the centre is extended. And, consistently with theory too, we find the deviation of the north pole of the needle, which, with the centre of the plates above the compass, had been easterly, having become westerly, when the centre falls below.

From these investigations, therefore, we may satisfactorily conclude, negatively at least, that whatever be the ratio of the capacity in iron substances, generally, of various proportions as to surface and mass, for magnetism terrestrially induced, such ratio is not (as from results in particular cases had been inferred) in accordance with the quantity of the superficial measurement. Something of the nature of the actual law by which the receptive capability of iron for induced magnetism is governed, will be elicited, I trust, by the considerations embodied in the next section.

SECT. V.—*Considerations respecting the actual Law by which the* QUANTITY *of Magnetic Energy, terrestrially induced in ferruginous bodies, is governed.*

FROM experiments and investigations of unquestionable character, as to the facts elicited, Professor Barlow and the late Captain Kator came to a like conclusion in respect to the (apparent) *superficial* nature of the magnetic influence terrestrially induced. From personal investigations, which I presume to be equally unquestionable in their character and results, the very dissimilar conclusion has been derived, that the ratio of magnetical power thus induced has relation to the mass rather than to the surface.

The *facts* elicited by these different investigations, therefore, being held to be equally unquestionable, we are naturally led to a particular scrutiny of the *conclusions* drawn from the facts, with a view to the reconciling of the apparent discrepancies, and so preserving the whole series of researches from being mutually neutralised by apparent inconsistency or incompatibility.

A due consideration of certain differences in the character or form of the bodies experimented on, will, I am persuaded, enable us satisfactorily to clear the difficulty.

In the experiments described in the foregoing section, the portions of iron employed were all of a comparatively *slender* or elongated form, whilst in the other experiments, with which these are compared and contrasted, the various ferruginous bodies whose magnetical character was tried, were particularly *massive*,—a form which must necessarily bring them under influences calculated to restrain the magnetical development, and that to a degree, or in a manner, of which the experimenters seem not to have been aware.

As this is a subject of extensive operation and vast importance in practical magnetics, it may well deserve particular exposition in its application to our present object,—the reconciling of apparent discrepancies in experiments on the terrestrial inductive influence.

One of the grand and fundamental laws of magnetic action consists in the directing or controlling influence of a body in the magnetical state on the magnetizable elements, so far as they are free to change, of any other proximate body. This influence, which in our considerations on magnetical induction we have sought to elucidate, always tends to develop the magnetic condition with polarities of the *contrary* name,—the dissimilar polarities, according to the familiar law of magnetism, being mutually attractive, and

the similar polarities repellant, of each other. Thus the *north* pole, for instance, of the dominant or master-magnet, in any magnetising operation, by its simple and quiescent inductive action, develops, in the nearest parts of any contiguous ferruginous body, *south* polarity, and so, that magnetisms, *molecularly considered*, of the same name, and therefore *mutually repellant* among themselves, pervade that entire section of the mass. The effect of this molecular repellancy in the section of the magnet endued with the same polarity, is to counteract the inductive influence of the proximate magnet, and to yield a statical result of *less energy* than that which otherwise would be due to its actual magnetical capacity. Hence the inductive influence acting from without, and the molecular repellancy operating within, are found to be antagonistic forces; but not forces, as we have formerly shown, acting in equable or uniform relations. For, in regard to the statical powers of *permanent magnets*—comparing those of like form and quality—we found these antagonistic forces to act in such wise, not only that the larger masses of *similar* form were less strong, proportionally, than the smaller, but that, in masses of a given length, the increase of the power was in a ratio so different from that of the mass, that, beyond certain limits, varying with the quality

and hardness of the steel, augmentations in the mass almost ceased to be influential. Thus, it was found, that in combinations of cast steel plates, of a spring-temper throughout, being 24 inches in length, 1·5 inches in breadth, and ·042 inch in thickness—a maximum power (as to any practical gain) was obtained by a pile or fasciculus of twenty-four in number, or an inch only in thickness.—[*Results*, vol. i. p. 114.] And the mere inspection of the curves in Plates III. and IV. vol. i., resulting from the projection of the magnetic energies of various qualities and kinds of steel plates and bars in combination, will be seen to indicate the correspondent law, where, in all cases in which the combinations had been carried sufficiently far, the curve is at length found to fall into almost complete parallelism with the line of abscissæ.

Now if this law, as to the modified relation of power to mass in permanent magnets, extend to the case of magnetism in iron terrestrially induced (as there is good reason to believe), then we may find therein, I think, a satisfactory explanation of the apparent discrepancy betwixt the results we have obtained and those arrived at by Captain Kator and Mr. Barlow.

In the case of Captain Kator's experiments,—where a short solid cylinder of iron seemed to possess but small superiority in recipient mag-

netism over hollow cylinders, of like superficial dimensions — the application of the principles above stated removes all difficulties of explation, without resorting to the untenable position of the magnetism residing only superficially. For with permanent magnets, of the dimensions and structure of the iron cylinders here compared, we should have found, as our former investigations (vol. i.) clearly indicate, very nearly, if not precisely, similar results. A *hollow* cylindrical magnet, of moderately thick steel, being of a diameter as great as its height (as in the case of Captain Kator's comparisons), would no doubt be as energetic, in directive power on a compass, as a *solid* cylindrical magnet of the same superficial dimensions: not, however, because the magnetic energy is essentially superficial, but because the defective sustaining power in the metal yields dominancy, where the massiveness is very considerable, to the antagonistic repellancy of the molecular magnetisms. And that a law analogous to this now applied illustratively really pertains to iron terrestrially magnetized, we have the strongest indication in the experiments of the preceding section. For the results unequivocally show a gradual diminution in the quantity of force gained by the progressive combination of iron plates; so that, whilst a single plate is found to have an energy, as indicated by

the tangent of the angle of deviation, of 711, two such plates, in addition to eight previously combined, only yielded an augmentation from 2077 to 2202, or 125. This rapidly diminishing effect of additions to the mass might, at first sight, seem to indicate that, had the combination been duly pursued, the power, at no great augmentation of numbers, would have reached a position beyond which additions to the mass could only in a very feeble degree be magnetically available. And to this condition the diagram prefixed to the RESULTS of the Investigations of the chapter now before the reader would appear to point. But the extensive enlargement of *bulk*, for masses of any given length, brings in a new element of receptive capacity for induced magnetism, which prevents, in strictness, the attainment of an absolute maximum.

It may be proper here to notice, whilst making the foregoing comparisons betwixt permanent magnets, and iron magnetized simply by terrestrial influence, that we do not hold the cases as strictly parallel, but as cognate and sufficiently analogous to be fairly comparable. For the sustaining power, which, in the case of the steel magnet is that of fixidity in the constitution of the metal, is, in the case of iron, the terrestrial induction acting so as to uphold the magnetism

developed by its own influence. The principles, however, by which the quantity of magnetism sustained is regulated, are in all cases kindred, and yield, as we shall see, notwithstanding the modifications in the antagonistic forces, corresponding results.

In the case of *unannealed* sheet iron, though the progressively diminishing effect, magnetically, of additions to the series of plates combined, was more slow than with similar plates which had undergone the annealing process; yet the same law, as to the tendency to approximate a maximum by a due extension of mass, was obviously indicated by the ratio of the deviations yielded by the advancing combination. For in this series of experiments it was observable, that the power developed in the *first* couple of plates, by terrestrial induction, was twice as great as that which was added to the magnetical force by the fifth couple in the fasciculus.

It must be borne in mind, however, that the operation of this principle, as now stated, applies to what we may call *massiveness* of form, rather than, simply, weight or mass. In the case of *straight-bar magnets*, it was concluded from former investigations,—[*Result*, No. 10, p. 328, vol. i.] that whilst those of large dimensions are less powerful, with respect to their masses, than small magnets to which they are proportional in

all their dimensions; and whilst the increase of the dimensions continually deteriorates from the quantity of energy due to the mass,—yet magnets may be combined in such *proportional dimensions*, with a constant increase of power, *ad infinitum*. But in the case of magnets not increased in *all* their dimensions whilst the mass or bulk is enlarged, the increase of power rapidly deteriorates from the proportion of the mass, till, under continued additions to the thickness, as before stated, an approximation as it were to a maximum, effectively considered, is attained. It is with respect, therefore, to thickness, or bulk, or massiveness in iron bars, or other elongated bodies, of any special length, that the deteriorating action of the force inherent in the metal, so effectually limits, magnetically, the operation of increase of mass.

Applying these principles, then, to the case investigated by Captain Kator, where a cylindrical form of iron was adopted of the most massive proportions, a near approach to a maximum of capacity for induced magnetism might be reasonably expected to occur, not at the extent of a solid mass of iron of a diameter equal in measure to the height, but in one, if solid, of inferior diameter, or if hollow, of very moderate thickness. Had the cylinders, compared by Cap-

tain Kator, however, as in our case, been of *many diameters* in length, and so, proportionally, much less massive, different results, most certainly, would have been obtained.

The same considerations apply, likewise, to many of the experiments by Mr. Barlow, from the results of which the idea was gathered, that the magnetic principle resides chiefly in the surface, or is of very superficial penetration in the iron, terrestrially magnetized.* That solid shot, and shells of three-fourths their weight, should yield the same results, was simply the effect of the neutralizing energy of the inherent magnetisms in such massive bodies. For as, among all possible forms, that of the solid sphere is the *most massive*, it follows that the shell or hollow sphere must be proportionally thin wherein the deviating magnetical energy, with equal surfaces, attains its maximum. Such maximum, indeed, might be expected, I conceive, in *cast-iron* shells considerably thinner than those employed; for with hollow spheres of *malleable iron*, the capacity of which, for magnetism, is greater than that of any other quality, the investigations led to the consistent inference that a

* "Essay on Magnetic Attractions," pp. 48, 50, 55, etc. The extent to which the magnetic principle seemed, from Mr. Barlow's experiments, to penetrate, was such, as to require a thickness (in iron-plates a foot square) of, probably, one-twentieth of an inch.

singular thinness of metal might yield a magnetic power equal to that of the solid cast-iron ball.

Diverse, now, as the conclusions to which, in different hands, the experiments above referred to seemed to point; there is found, on a reflective comparison, no discrepancy in the facts elicited. On the contrary,—as our reference to principles affecting the magnetical capabilities of ferruginous bodies generally will, I trust, have satisfactorily proved,—the facts so variously brought out and their indications so differently read, are found to be strictly accordant with determinate magnetic laws.

Sect. VI.—*Further Exposition of the Law of Massiveness, in regard to the Capacity of malleable Iron for Magnetism terrestrially induced.*

Some months after the foregoing views were drawn up and prepared for the press, certain forms of experiments occurred to me by which it appeared probable that these views, if correct, would be at once verified and elucidated.

The first of these was the more accurate determination of the ratio of capacity with respect to massiveness, in a series of iron bars of various

and graduated thickness, being of like quality of iron and all of the same length. The length, for the advantage of comparison with former researches, I proposed to be 15 inches, and the thicknesses, in *square* and *round* iron, to extend from half-inch, by quarter-inch intervals, up to to two-inch bars. This series would have afforded a range of massiveness from seven and a half to thirty diameters in length, and might have served to extend and complete the investigations of which the results are given in table I., and also to have shown, more precisely, the effects of *annealing* on bars of regular quality, whose powers should have been previously determined in the condition of hardness left by the rolling. As I could not procure, in the country, any such series of bars, nor bars of different sizes, of the uniformity of the temper and quality of which I could have satisfactory assurance, I made application to the manager of one of the large iron-works in Yorkshire for the supplying of the requisite bars. But my application, unfortunately, was not responded to,—the only instance, I remember to have met with, in which the importance of scientific research was not deemed sufficient to compensate for the little trouble, to parties engaged in great concerns, of furnishing specimens of their manufacture out of the usual course of business.

For the second form of experiment however, —which proved sufficient for my principal object and perfectly satisfactory,—the materials that might suffice were found to be easily attainable on the spot.

The rudimentary idea, in the proposed experiment, was to compare the magnetical powers, terrestrially developed, of *hollow cylinders* of iron with those of *solid bars*, all of equal and corresponding dimensions, externally,—the comparison to be made in sets or pairs of the tubes and bars in considerable variety as to the lengths. The lengths, it was designed, should comprise such a range, from dumpiness to elongation in the proportions of the principal dimensions, as might serve to indicate the point or position in which, on the one side, the hollow cylinder might equal the power of the solid, and, in which, on the other side, the entire mass of the solid bar might be mainly available for the augmentation of the power.

For this enquiry, portions of an inch and a half bar of round iron were procured to match the thickness (nearly) of some pieces of tubing which I happened to have by me. Of each description of iron, lengths of 3, 6, 9, and 15 inches were cut off cold, and the ends filed square so that they might stand firm and upright upon the deviation-board, and might have also pretty

good contact when placed on each other for the formation, by combination, of additional lengths; —for designing a series with regular intervals of three inches, from 3 to 24 inches in length, I had previously ascertained experimentally, that any two (or even more) bars in the upright piles yielded, with but unimportant differences, corresponding results with those of equal lengths in a single piece. The thickness of metal in the tubing was about ·17 of an inch, and the mass, compared with that of the bar, was as one to two and a half, nearly,—the external diameters being very much alike.

By means of the several sizes of the tube and bar selected, their respective magnetic powers could be satisfactorily compared through all the variety of massiveness from two to sixteen diameters in length. And by the addition of similar lengths of round-bar iron of an inch in diameter, being not very dissimilar to the tubing in the *weight* of corresponding lengths, yet of a size small enough to be inserted within the tubing—two further comparisons were provided for, viz. the ratio of the magnetic powers of the tubing with that of solid bars of similar mass, and the ratio of the powers of the pieces of tubing, as augmented by the smaller bar-iron within, with that of like lengths of the larger solid bar.

It was designed, under the original notion of this investigation, to follow out the plan of table No. 1, by a final comparison of the powers of the various sets of cylindrical iron in their crude state, and after their being annealed. And this, to a considerable extent, was attempted. But the result indicated, that no reliance could be placed on the condition of the bar-iron and tubing, as to their having undergone no change by incidental heating, since their first production into form. The attempt, therefore, to deduce any satisfactory comparison on this particular point was abandoned; and the whole of the bars and pieces of tube were subjected to a red heat, as affording the only chance of uniformity of condition, and the results, in the annealed condition, alone selected for being recorded.

The plan of the experiment, in respect to the determination of the magnetical powers of the bars and tubes, was similar to that of the former investigations. The various pieces of iron, being first freed from any accidentally acquired magnetism, were placed upright on the deviation-board, after the manner represented in figure 8, page 37, at the distance of six inches from the compass westward, measured from the centre of the magnetic action of the vertical iron to the centre of the needle. This arrangement, which admitted of the middle of the base of the *inch*

bars to be placed very nearly on the mark of six inches on the board, required the centre of the thicker iron to be removed a small but sensible distance beyond. In order to give the best effect to this simple and satisfactory mode of determining comparative magnetic powers, where the action of such *very short* cylinders, along with others, was to be tested,—the plane on which the lower ends of the cylinders were to rest was raised, by means of an evenly formed block of lead, a little above (about a quarter-inch) the level of the compass-needle. This elevation of the testing platform of the iron cylinders, served to give somewhat greater dominancy in the shorter pieces, to the action of the lower polarity, and thus to render the resulting action of the two antagonistic magnetisms on the compass, the more decided and satisfactory.

A considerable number of trials of the magnetic powers of the various bars and tubes, on this plan, were made. In many cases, six, eight, or more observations were made on the powers of a single bar, and in every case the power, with each end alternately upward, was ascertained. The general means of the powers of each particular bar and tube, together with their respective weights (registered to the nearest 50 grains) are, for facility of comparison, given at one view in the following table.

TABLE III.—Deviating Powers, derived from Terrestrial Induction, of *annealed* Bar and Tubular *round* Iron, of various Lengths, for the Exposition of the Law of Massiveness in solid and hollow Cylinders. Distance betwixt the centre of the Needle and the focus of attraction of Bars six inches.

No. of Expt.	Length of Bars. Inches.	Round Bar Iron, 1·5 inches Diameter.			Tubular Iron, about 1·5 inches Diameter.			Round Bar Iron, 1 inch Diameter.			Tube with inch Bar in side.		Ratio of 1·5 in. Bar, col. iv. and Tube, col. vii.
		Weight in Grains.	Mean Deviation	Tangent.	Weight in Grains.	Mean Deviation	Tangent.	Weight in Grains.	Mean Deviation	Tangent.	Weight in Grains.	Mean Deviation	
	i.	ii.	iii.	iv.	v.	vi.	vii.	viii.	ix	x.	xi.	xii.	xiii
			° ′			° ′			° ′			° ′	
I	24	85,100	33·30	662	35,500	24·14	450	38,200	25·25	475	73,700	33·28	147 : 100
II	21	75.200	29·55	575	31,000	22·33	415	33,700	22·28	414	64,700	29·47	139 : 100
III	18	63,800	25·45	482	26,600	20·10	367	29,150	18·50	341	57,750	25·29	131 : 100
IV	15	53,400	20·50	380	22,200	17·13	310	24,600	15·55	285	46,800	21·3	123 : 100
V	12	42,100	14·52	265	17,500	12·50	228	18,150	10·52	192	35,650	15·7	116 : 100
VI	9	31,700	9·45	172	12,800	8·34	151	13,600	6·57	122	26,400	9·40	114 : 100
VII	6	21,800	4·57	86·6	8,800	4·36	80·5	9,100	3·10	55·3	17,900	4·40	108 : 100
VIII	3	10,400	1·0	17·5	4,400	0·57	16·6	4,550	0·34	9·9	8,950	1·1	105 : 100
Amounts		383,500	—	2640	158,800	—	2018	171,050	—	1894	331,850	—	—

Considering the various sources from whence irregularities might be expected to arise,* the deviations produced by the different bars and tubes, in their respective series, are here seen to be remarkably consistent and satisfactory. And, it can hardly fail to be remarked by the observant reader, that the whole of the records exhibited in the table go to the support of the hypothesis we have sought to elucidate and test,—of the actual operation of two antagonistic forces having relative dominancy varying with the massiveness of the form; so that in the most massive forms, such as that of the cylinder of three inches, the capacity of the tube is the same, very nearly, as that of a solid bar of two and a half times its weight; whilst in the least massive, such as that of the twenty-four inches length, the power of the tube is one-third less than that of the corresponding bar, though the ratio of the masses remains the same as before.

* Three sources of irregularities may be noted as calculated to influence the precision of the results:—1st. The probable want of accordance in the quality of the iron of the bars and tubes. 2d. The imperfect and desultory manner in which the annealing was done. And 3d. The rough adjustment of the tubes and bars to the specified lengths. But whilst these imperfections could not fail, in some small degree, to affect the precision of individual cases, or comparisons, they could in no wise vitiate the investigations in their leading objects, nor at all interfere with the soundness of the principles pointed out by the general series of deviations.

It will also be seen, exactly as predicated, that whereas the *special case* of the short or dumpy cylinder serves to confirm the result obtained by Captain Kator,—the case of the longer cylinders completely justifies our anticipations as to the necessary failure of that equality of magnetic powers in solid and hollow cylinders, of like external dimensions, when the degree of *massiveness* is greatly reduced.

Though the powers of the solid and hollow cylinders of three inches length did not actually come to an equality in our experiments, yet that such a condition was very closely approximated was shown by other experiments made on the shortest of the cylinders whilst laid on their side, so as to be but a diameter in height. In this case, no difference whatever could be observed betwixt the magnetism of the tube and that of the solid bar in their effects upon the compass. It is not improbable, indeed, but that a nearer equality of powers belongs actually to the shortest of our cylinders than, in the table, might appear. For on some special trials of their comparative powers at a shorter distance from the compass, where the difference of deviations being trebled, could be more exactly ascertained, the respective powers of the bar and tube gave the proportion of 101 to 100, and in another special case 103 to 100.

That the residence of the magnetic power is not superficial, nor limited in its penetration to an inconsiderable depth, such as the twentieth of an inch, will be seen, I think, to have complete demonstration in the facts exhibited in the table. For, if the power had been actually superficial, then should the tubes and bars, whose magnetic action, in a length of three inches was about equal, have also had equal action in all other lengths having similar superficial dimensions; whereas, under an uniform correspondence in the surface of the cylinders compared, their relative powers became more and more diverse, with the mere increase of the length, until, in the length of twenty-four inches, the solid bar had attained a superiority over the hollow cylinder in the ratio of nearly three to two!

In the comparison of the powers of the thick tubing (col. vi.) and those of inch-bar iron (col. ix.), being, in their similar lengths, of tolerably corresponding weights, there will be further seen (in respect to the more *elongated masses*) a very clear analogy, consistently with our deductions from the experiments recorded in sections iv. and v., betwixt the magnetic capacity of *solid bars* and that of *tubes* of similar length and weight. In the case of the two shortest cylinders (VII. and VIII.), indeed, the magnetism of the tubes is found to exceed that of the inch bars in the ratio of

about three to two; but, taking the whole of the series together, the differences of powers are obviously not greater than what may be satisfactorily explained on the principle very early established in our researches—that of the increase of the magnetic power, by the spacing of plates, or spreading out of the mass, and thus reducing the magnetic concentration by which the actual capacity is restricted of its due development. [vol. i. p. 128.]

Comparing, again, the powers of the thicker bar iron, col. iii., with those of the tubing with the smaller bars within, col. xii., a very remarkable agreement will be observed;—the powers, on the whole, being almost identically equal, though the weights of the two sets, as given in columns ii. and xi., differed in the proportion of about 38 to 33. But here again, we find a sufficient explanation in the general law before determined —as to the superiority in magnetic capacity of combinations of plates or bars over single masses of corresponding weight. [vol. i. p. 110.]

Finally, it may be observed, that the deteriorating influence of massiveness on the magnetic capabilities of iron bars, and the contrary effect of the diminution of the magnetic concentration by elongation of the bars or the spreading out of the mass, as in the tubes,—are conspicuous in

every department of the records embodied in the table. Thus the thick solid bars, whose weights, compared with those of the inch bars, were as 384 to 171 or about 7 to 3, had a superiority in magnetic power in the ratio only of about 7 to 5; whilst the *extended* mass in the tubes, whose weight was less than that of the inch bars in the proportion of about 9 to 10, gives a superiority in the power, simply it appears by the diffusion of the magnetism, of about 10 to 6, in the extreme case of the dumpy cylinders, and of 10 to 9·5 on the general average.

As regularly formed iron bodies—being of different but *proportional* dimensions, and composed of metal of the same quality and condition as to temper,—appear to possess magnetic powers proportional to their masses, nearly,—we may consider the *massiveness* with respect to the *proportions of the dimensions* in any particular case, without regard, in the general comparison, to the actual weight. And thus a convenient mode of describing the relative massiveness will be found in reducing the particular body of iron, by estimation, to the regular form, as a standard, for instance, of *square* bar-iron, and then considering the proportional massiveness as the ratio of the thickness to the length. For this reduction, the expression—

$$M = \frac{\sqrt{a}}{l},$$

l being the *length* of the bar, and a the *area* of its end or base, will conveniently serve for the indication of the massiveness, M, in every case of bar iron, whether round, square, or flat.

Hence, if the *massiveness* of a *cube of iron* be c, that of our flat bar xi., table I, of 15 inches by 1 and ·5 inch, would in round numbers, be,

$$M = \frac{\sqrt{a}}{l} = \frac{\cdot 7}{15} = \frac{1}{21\,c};$$

not, it will be observed, that such bar is, in massiveness, the 21st part of the cube of its length; but that the height of the cube of the base is the 21st part of the length; or familiarly, that it would take 21 cubes of its own thickness to make a pile of the height and mass of the bar.

In this form of comparison, the massiveness of the round bar of 24 inches in length would be $\frac{1}{18\,c}$, and that of the bar of 3 inches $= \frac{1}{2{\cdot}26\,c}$.

Another form of the expression, as applied to the particular case of the flat bar xi., table I., might be

$$M = \frac{\sqrt{a}.l}{l^3} \text{ or } \frac{\sqrt{a}}{l^2} = \frac{10{\cdot}5}{3375} = \frac{1}{321\,p},$$

p, in this form, being a square prism of the length and weight of the bar referred to, and $\frac{1}{321\,p}$, indicating the proportion of such bar to a cube whose side is correspondent, in measure, with the length of the bar.

Besides the deductions already drawn from direct comparisons of observations in table III., (to which we finally recur) in respect to the laws by which terrestrial induction is guided in its action upon bars and tubes of malleable iron of various corresponding lengths,—there yet remains a consideration, of some interest in the series,—that of *the ratio of the power with the length* in each particular size of bar or tube—which will require something more than a simple comparison of the observed deviations in order to its satisfactory development.

The simple comparison of the powers of the four series of bars and tubes respectively, at any of the *special* lengths subjected to experiment (where the circumstances and conditions were thoroughly correspondent) was calculated to afford just and conclusive results. But such simple comparison of the powers of any particular set of bars *in their different lengths*, would yield, because of a want of correspondence in the nature of the magnetic action in the series, a ratio, in respect to length, altogether at variance with the actual law. Thus comparing the powers of any of the sets of bars, as determined simply by experiment, for the length, say, of six inches, with those, as indicated in like manner by the tangents of the deviations of the compass-needle, for three inches, we find preva-

lently, the ratio of 5 to 1 in *power*, for a proportion of 2 to 1 in length. But the true ratio of the power is very different from this, because of the varying proportions of the action of the two polarities of the iron bars on the compass, whenever the length of the bars is changed. But the case may deserve more particular examination.

The action of the inductively magnetized bar on the compass, as in any other case, is the resultant of the two polarities, derived from all the magnetic forces therein, in which, the northern pole being nearest to the compass, and acting most favourably, is the most dominant. The relative powers of the two polarities, consistently with the general law, must be in the inverse ratio of the squares of their distances. In the case before us, whilst the distance n, of the lower or northern pole, is uniformly six inches, that of the upper pole, s, varying with the length of the bar, l, will be

$$s = \sqrt{(n^2 + l^2)},$$

because s, in the particular position of the bar adopted for this experiment, is correspondent with the hypothenuse of a right-angled triangle, of which the distance n, is the base, and the length of the bar the perpendicular. And, hence, the deviation produced on the needle is the result of forces represented by n^2 and s^2, inversely, acting in opposition to each other.

But, it is observable, in respect to this particular case, that whilst the lower pole, acting in, or very near, the same horizontal plane as that in which the needle revolves, exerts its *full* force upon the needle; the upper pole acts obliquely, and therefore with a *loss* of power; so that the general resultant of the magnetic powers of the bar becomes $n^2 - s^2$, inversely, or as $\frac{1}{n^2} - \frac{1}{s^2}$, directly, *reduced*, as to the latter force, in the ratio of s to n. For, it is sufficiently obvious, that, under the oblique action of the upper polarity, it is the horizontal portion only of the two forces into which s is resolvable, which can have influence on the deviations of a horizontally acting needle.

Hence, it is further observable, that whilst the actual force exerted by the upper poles of any series of bars of different lengths, must be in the inverse ratio of the squares of their respective distances, s, s', s'', etc.—the effective deviating powers must be reduced below this ratio with every addition to the length; and so, that whilst with a bar, *indefinitely short*, the power of the upper pole, being at a maximum, would totally neutralize that of the lower,—with a bar *indefinitely long*, the upper pole acting at a minimum, would leave the entire undiminished power of the lower pole to operate in the deflection of the needle.

Guided by the principles now elucidated, we are enabled to determine the individual and proportional action of each polarity in iron bars or tubes of different lengths,—in the particular form of experiment, from which the results of table III. are derived,—and thus, by the comparison of the separate powers of the northern, or dominant, polarity, to obtain the ratio of magnetism terrestrially developed with relation (in bars of corresponding quality, form, and thickness,) to the length.

As it will simplify the calculation, without materially affecting the proportional results, we shall consider the two polarities, induced in the bars or tubes, as being concentrated at their extremities (instead of a short distance within), so that the actual lengths may be taken for the distance of the magnetic foci of each bar; and we shall also assume the level of the lower, or northern, magnetic focus of each bar, when under experiment, as being coincident (as it was nearly) with the horizontal plane of the compass needle.

Selecting the four lengths, only, of 6, 12, 18, and 24 inches, which, for readier comparison with the distance of the lower pole of the bars (uniformly six inches), from the centre of the needle, may be called 1, 2, 3, and 4; we find the distances s, s', s'', s''', belonging to each, to be 1·414,

2·236, 3·162, 4·123, nearly. The reciprocals of the squares of these distances, representing the absolute force exerted by the upper poles of the bars at their respective distances from the compass, are ·5, ·2, ·1, ·06,—the force of the lower poles being uniformly 1; and the proportions of the horizontal influence of these forces, acting deviatingly on the needle of the compass, are ·35, ·09, ·03, ·014. Hence these forces, being directly converse in their action to those of the northern or dominant pole, must serve to reduce the individual influence of the northern poles of the series, considered always as 1 in the ratio, leaving the resultant magnetic action of each bar, 1 — ·35, 1 — ·09, etc. = ·65, ·91, ·97, ·986; hence, again, by the application of these resultant forces to the observed deviations produced by the various bars and tubes, according to their respective lengths, we may derive from the results of the table the proportional powers of the northern poles separately, and thus obtain distinct ratios for each and all of the different classes of bars and tubes.

Taking, for example, the observed deviations produced by the series of 1·5 inch solid bars, we have 4° 57′, or tangent 86·6, as the apparent power of the bar of six inches in length. The proportion of 0·65 : 1 : : 86·6 : 133, gives the proportional action of the north pole separately.

In like manner the proportion of 0·91 : 1·00, applied to the deviating action of the bar of 12 inches, or tangent 265, gives 291, as the tangent indicative of the power of its north pole separately.

The entire reductions of the observed, or resultant, magnetic action of the various bars, into the relative powers of their northern poles taken separately, are comprised in the following table.

TABLE IV.—Comparative Force of the *northern* Polarity in three Series of Bars and Tubes of different lengths under Terrestrial Induction, with the proportional Power of each Series, calling the 6-inch length 100, calculated from colums iv., vii., x. of Table III.

Length of Bars. Inches.	Tangents of Powers of North Poles separately.			Proportional Powers of North Poles in each Series.		
	1·5 In. Bar.	1·5 In. Tube.	1 In. Bar.	1·5 In. Bar.	1·5 In. Tube.	1 In. Bar.
i.	ii.	iii.	iv.	v.	vi.	vii.
6	133	124	85	100	100	100
12	291	251	211	219	202	248
18	497	379	352	374	306	414
24	671	456	482	505	368	567

Whilst these reductions confirm in every way the views already adduced with respect to the varying effects, in solid and tubular iron, of

massiveness and elongation, etc., they enable us to correct the undue rapidity of apparent increase of power with increase of the length of the bars of each series. Thus the ratio of increase in the 1·5 inch bars, which, taking the resultant action of the two polarities, (table III., col. iv.,) appeared to be 86·6, 265, 482, 662, or 100, 306, 557, 764, is found, on the separation of the converse action of the upper pole, to be (as fairly represented by the proportional powers of the series, col. v., table IV.,) 100, 219, 374, 505. In like manner, the proportion of the longest bar to the shortest, in the series of 1·5 inch tubing, which appeared from table III. to be as 450 to 80·5, or as 561 to 100, in reality becomes as 368 to 100; whilst the proportion of the longest and shortest of the bars, in the inch bar-iron series, which, from the compass deviations, appeared to be as 475 to 55·3, or as 859 to 100, becomes, after the process of reduction, as 567 to 100.

SECT. VII.—*On the recipient Susceptibility of Hard Steel for Magnetism terrestrially induced.*

THE comparative susceptibility of various kinds of iron and steel for magnetism, terrestrially induced, constituted one of the subjects of enquiry

with Professor Barlow when engaged in the experiments which yielded the materials for his instructive "Essay on Magnetic Attractions." The results obtained gave "the proportional magnetic powers of different descriptions of iron and steel," as expressed (page 135 of that Essay) in these ratios: —

Malleable iron . .	100	Shear steel, hard . .	53
Blister steel, soft. .	67	Cast iron	48
Blister steel, hard .	53	Cast steel, soft . .	74
Shear steel, soft . .	66	Cast steel, hard . .	49

But these results, though derived from bars, in some instances of different dimensions, represent, in consequence of their reduction to a common standard of malleable iron, the special case of bars of 24 inches in length, and an uniform measurement as to thickness. From considerations derived from the personal investigations recorded in vol. i.,—in respect to the difference in the proportional magnetic capabilities of varieties of steel when compared in massive or slender bars,*—to me it appeared, that the proportions of magnetical qualities determined for a *single case*, such as that referred to, could not apply for *general* comparisons. For having determined, in respect to the results derived from *thin* plates of steel,—as to the superiority of magnetical capacity, in that particular case, of tempered

* See diagrams Nos. 1, 3, 4, and 6, in Plates II., III., and IV.

steel over hard steel, and shear steel over cast steel, — that the proportions of power were changed, and the apparent superiority even reversed, when *thick* or bulky masses were substituted for the thin plates,—it seemed reasonable, from analogy, to expect, that some similar law would probably hold in respect to magnetism terrestrially induced. And, if so, it must of necessity result that the ratios obtained for a special case, as above given, would be found to vary greatly, and, possibly, to the extent of *reversing* the apparent quality as to superiority, and the proportional magnetic powers, in case of comparison of the like description and length of bars in greatly augmented masses in bulkiness of form.

Though my enquiries, herein, extended but little beyond the comparison of *hard thin plates of cast steel*, with the results in respect to *malleable iron*, described in the foregoing sections,—they served sufficiently to show, by the alterations produced in the proportions of magnetic power in the two qualities of metal under progressive and accumulated combinations of plates, that the anticipations, which the analogy referred to had suggested, were well founded.

A series of ninety-six thin plates of cast steel, as hard and nearly as brittle as glass, were selected for comparison with those of rolled iron and iron bars. The sizes and weights of the

steel and iron plates corresponded pretty well; and the plates and bars were very similar as to length. The steel plates were 15·25 inches long, 1·5 inches broad, and about ·028 thick, and of the weight, on an average, of 1078 grains. The deviating powers of these plates, singly, and as combined in various numbers, whilst placed upright at the distance of six inches from the centre of the compass, and in the line of its west point, (precisely after the manner adopted with respect to the iron plates,) were as follow:—

TABLE V.—Magnetical Powers, terrestrially developed, of a Series of hard cast-steel Plates, when placed in a vertical position, six inches from the Compass.

No. of Plates.	Weight in Grains.	Sets of Expts.	General Mean.	
			Deviation.	Tangent.
1	1078	6	° ′ 0·18·5	5·3
2	2156	3	0 38·6	11·2
4	4312	3	1·1	18
6	6468	2	1·17·5	23
8	8624	2	1·42	30
10	10,780	1	1·59	35
12	12,936	1	2·44	48
16	17,248	1	3·30	61
20	21,560	1	3·55?	69
24	25,872	4	4·38	81
48	51,744	1	8·10	144
72	77,616	1	11·25	202
96	103,488	2	14·22	256

Comparing these deviations with those of malleable iron annealed, we find, in the case of a *single plate*, (allowance being made for the small difference of weight,) a superiority in magnetic capacity in the soft iron of about twelve to one. (Table I., section III.) But comparing twelve plates of steel, weighing 12,936 grains, with ten plates of annealed iron of 12,467 grains, the proportion of superiority in the iron is found to be reduced to about five to one. And comparing, again, forty-eight plates of steel, of 51,744 grains weight, with a *solid* round bar, (No. IV., table III.), being of the same length and proximate weight of 53,400 grains, we have a further reduction in the proportion of magnetical powers of the soft iron and hard steel, (making a fair allowance for the 1656 grains difference in the masses,) to two and a half to one.

But small doubt, therefore, as appears to me, could exist, especially when connecting these indications with the analogy of formerly determined laws,—but that a due increase of the corresponding masses, in iron and steel plates, might, at length, have been found to yield a superiority of capacity in hard cast steel over malleable iron for magnetism terrestrially induced; and thus, not only to alter, but ultimately to reverse, perhaps, the proportions of power as derived from the comparison of slender bars or plates.

The further deductions, however, from these experiments, may be conveniently thrown into the general results at the end of the chapter.

SECT. VIII.—*On certain Attractive and Directive Influences resulting from terrestrially-induced Magnetism.*

1. THE attraction of iron for iron, as *a lifting power*, when the magnetizing influence is solely terrestrial, was the first application attempted of the information gained by the preceding researches. For where the action on a compass by iron terrestrially magnetized was so powerful, there seemed to be good reason for expecting some perceptible attractive effect on small portions of iron: and when the *annealed* iron plates had indicated such great superiority over crude iron, there was additional promise of a successful result on such plates being employed.

These expectations being satisfactorily realized, and to an extent which might incline some readers to repeat the experiment, I give the description of the particular case, as being equally applicable for the object and more specific for guidance than a general description of the plan and process.

[10. *Exp.*]—One of the series of *annealed* iron

plates, whose magnetical properties are indicated in table I., was selected for the original trial. Its length, as before described, was about 15 inches, breadth 1·5 inches, and weight about 1250 grains. But these particular dimensions, provided the length of the plate be ten to fifteen times the breadth, and the annealing at a red heat be duly effected, are of no importance. The only preparation, as to the plate selected, needed for the experiment, was to provide for a good contact with the *attracting* end. This was effected by filing it smooth, rubbing it on a turkey-stone, and then polishing it on a razor strop.

Thus prepared, with a variety of small portions of iron, duly polished for lifting, at hand, the plate, on being held in an upright position, was found to have satisfactory polarity and very obvious attractive capabilities. Two very small brushes of fine iron filings adhered to the corners of the polished extremity, and small portions of iron wire were either moved or lifted by its attractions.

Being doubtful whether the filing and polishing processes, however, might not have augmented the magnetical capabilities,—the plate was carefully neutralized and tested by its inaction on a small compass, when, placed in the magnetical equatorial plane, within a couple of inches of its

centre. It was now quietly raised into an upright position, when its attractive power was as before,—bits of fine wire were lifted, and small polished sprigs, or brads, the largest weighing about three grains.

[11. *Exp.*]—On trial of the thick iron plate, No. ix. table I., weighing 3830 grains, it was found to possess somewhat higher capabilities in attractive force. It lifted, by induced magnetism from the earth solely, small tacks with polished points, and, in its best performance, a nail of 10 grains.

[12. *Exp.*]—Combining about a dozen iron plates together in a bundle, having the plate with the polished end slightly projecting in the middle of the mass, some further capabilities, in attractive force, were elicited, but by no means in any measure of correspondence with the increase of the mass. And on trying, finally, a large iron poker of several pounds in weight, after being totally neutralized as to magnetism in the plane of the magnetic equator of the earth, the lifting power was not found to be greater than that of a single annealed plate. For with the pointed end nicely polished, the sustaining of small brushes of iron filings with small sprigs of two to three grains in weight, constituted its

utmost attractive capabilities from magnetism induced into it when in an upright position.

2. As iron, on the near approach to it of a magnet, has first a polarity developed in it, and then is attracted by virtue of the polarity so elicited,—it seemed reasonable to expect that a needle, or bar of iron, rendered magnetic by terrestrial influence, might, if so suspended as to revolve with little or no friction, be in like manner acted on attractively or directively, by the master-influence from whence its polarity was derived. In other words, it seemed reasonable to expect, that a needle, or bar of iron, duly adapted for receiving magnetism from the earth and for moving in conformity with the very delicate tendencies of the developing influence, might act as a *compass needle*, ordinarily magnetized, and adjust itself into conformity with the magnetic meridian of the earth.

A needle of iron, however, adapted by suspension to traverse in a horizontal plane, could only act, it was evident, with extreme feebleness; and, near to the lines of east and west direction, where there could be little or no polarity induced, no power adapted for adjustment could be existing. But the abrogation of magnetic influence in such positions, as well as the extreme feeble-

ness of influence in others, might, as appeared to me, be overcome by suspending such iron needle in a position approaching that of the dipping needle, or by bending its extremities so that its general mass might intersect the plane of the magnetic equator at a larger angle than the horizontal needle. These expectations, as shown in the following experiment and description of an *iron compass needle*, were, also, successfully realized.

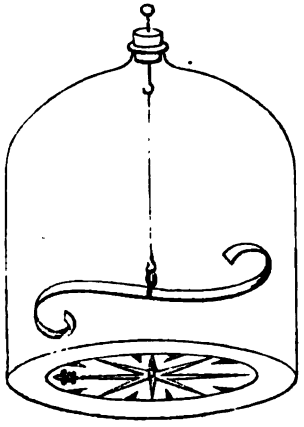
[13. *Meridional Iron Needle.*]—The quality and condition of iron which had already been proved to have such high magnetic capabilities,—viz. annealed rolled plate—was selected for this object. A slip of about 15 inches long, and 0·75 inch broad, was bent, reversely at the ends, in form of the architectural cyma or ogee, and, in this condition, adopted for the proposed needle. A piece of thin brass wire was bound round the middle and centre of gravity of the curved plate, with a loop rising near an inch perpendicularly from its flat surface, which attachment, whilst it provided for the due suspension of the needle by means of a few fibres of silk, likewise served to keep the curved ends steadily in a vertical plane. The apparatus thus prepared, at the cost of only about twenty minutes attention and manipulation, was suspended, for trial merely, from a small

scale-beam pillar, and, to shield it from currents of air, covered with a bell-shaped glass. It began immediately to move in wide and sluggish oscillations, and, at length settled, but not exactly, in the direction of the magnetic meridian. Ascribing the error of position to torsion in the silk fibres, which were taken from a loosely twisted thread,—the torsion was removed, by suspending a bunch of keys of not very dissimilar weight to that of the needle to the silk, and the needle was then replaced under these more favourable dispositions. The action was now altogether unbiassed, and the needle, when it settled, was found to be perfectly conformable to the direction of the magnetic meridian.

Suspecting, however, that the very effective action of the instrument, in its meridional adjustment, might be due, in part, to magnetism acquired under the operation of bending the iron slip into the designed shape,—I removed the needle, and so completely neutralized its acquired magnetism that it scarcely affected, sensibly, when in the plane of the magnetic equator, a very small compass needle at the distance of two inches. There being now nothing which might aid the ordinary magnetism of position, terrestrially induced, the needle was restored to its place within the glass shade. It still traversed, perhaps a little more sluggishly but as decidedly

and characteristically as before, and ultimately assumed the true magnetic direction. It was found, too, to obey extraneous influences, such as the polarity of a bar of iron held vertically near either of its poles, after a similar manner, though less promptly, to the common compass needle. Thus, whilst governed in its direction by so slight and transient an influence as that of terrestrial induction, it was susceptible of *repulsion* from the incongenial polarities of a poker, (as well as of the ordinary attraction,) and when its north pole had been repelled by proximity of the lower end of the poker, its recession could be arrested by removing the poker to the other side, and a reverse motion produced.

FIG. 9.



The above figure is a representation of this simple but really effective *meridional iron-needle*,

in the form originally adopted. The suspension silk, it may be noticed, is attached to a small S shaped hook at one end, and to a little brass ring at the other,—the former passing into the loop of wire on the needle, and the other being adapted for hanging to the hooked end of another wire piercing the centre of the cork at the top of the glass, by which wire the height of the needle can be regulated to a convenient position above the table. A compass card, adjusted with its centre exactly in the vertical line of the suspension thread, and with its rhombs correspondent with the earth's horizontal polarity, indicates the degree of correctness, or measure of deviation, in the position assumed by the needle.

Sect. IX.—*On the Nature of the Magnetism terrestrially induced, as compared with that in permanently Magnetic Bodies.*

That the condition of a bar of iron or steel, magnetized by terrestrial induction, is essentially similar, except as to permanency, to that of a bar of steel possessing the quality of a real magnet, would be the simple and natural inference, I think, from a general view of the correspondence of their respective phenomena. But other views having been set forth, as deduced from investiga-

tions of the highest scientific order, and diversities in theory incompatible with each other having been arrived at by different magneticians,—some observations, in which guidance from the researches in the foregoing pages may essentially aid us, may here be submitted, towards the elucidation of the actual principles, and the explanation of the apparent discrepancies in the different conclusions.

A quotation from the "Essay on Magnetic Attractions," (page 180), will serve, in few words, to define the adverse hypotheses to which we refer. According to Coulomb, Mr. Barlow observes, "Every ball or mass of iron becomes by induction from the earth, a temporary magnet, having its north and south poles at its extremities, or at those of the line corresponding with the dip of the needle in the place of observation. Whereas, agreeably to the hypothesis I have advanced, the latent magnetism of the ball has merely polarity given to it; but it is distributed over the surface, and has its centres of action indefinitely near to each other in the centre of the ball."

In the former view—to a correspondence with which all my personal researches tend—the temporary magnet should, like the permanent magnet, have a concentrated attractive influence in its poles, rather than a diffuse and superficial energy, according to the latter view, *generally* distributed.

Certain views, prevalently, I believe, entertained, on the [supposed] incapability of iron, terrestrially magnetized, "of attracting and giving direction to the lightest and most freely suspended needle of soft iron, or of unmagnetized steel,"—were in favour of Mr. Barlow's hypothesis,—which hypothesis seemed further to be supported by a special experiment with an iron ball, in which, on trying the action of the lowest portion of its surface on fine iron filings floated on a surface of water, not the slightest motion of the filings, such as to indicate the existence of the pole in question, could be observed.*

Our experiments (11 and 13, section VIII. of this chapter), conclusively show, that a soft iron needle, devoid of all magnetism but that due to terrestrial induction, *is* susceptible both of attraction and repulsion from a bar of iron similarly magnetized, as well as of a compass-like adjustment in the magnetic meridian; and that iron bars or plates, terrestrially magnetized only, possess an attractive power in their poles sufficient, when duly polished, for sustaining fringes of iron filings and small nails. Hence these properties of the true magnet, supposed to be lacking in magnets of terrestrial induction, are proved to be existing in due proportion, in respect to the relative energy, in the soft iron bars. Nor are the like properties, as I experimentally determined,

* Magnetic Attractions, pp. 113 and 181.

altogether wanting in sheet iron cast into a circular figure, like a hoop, and, by consequence, it is to be presumed, not utterly separate from, or incomparable with, *spheres* of iron.

[14. *Exp.*]—Taking a long slip of thin sheet iron, 2·3 inches broad, I cast it into the shape of a hoop, 12 inches in diameter. In the middle, opposite the joining, and also at the intermediate quadrant, I filed and polished a portion of the exterior surface, in a broad line across the hoop. Then demagnetizing the hoop, with a special regard to neutrality at the parts to be tested, I applied fine iron filings on a paper beneath, whilst the hoop was held in a vertical plane with one of the polished sections in the place assumed to be the lower pole. The *attractive* action of the pole which, on being presented to the compass, was found to have considerable power, was here *decided*, but very feeble. The polarity, however, was found to be sufficient to attract minute and scattered portions of the filings, not, as I proved, by common adhesion, but magnetically; for on examining them with a microscope, I could perceive some strings of minute particles descending, perhaps, the twelfth or tenth of an inch below the place of their attachment.

[15. *Exp.*]—This experiment was repeated with a *flat ring* of annealed iron, and with im-

proved efficacy. The ring, which was closed, but not welded at the joining, was about seventeen inches in diameter, and was formed of iron an inch broad and a quarter of an inch thick. The outer edge at the joining, and also exactly opposite it, was nicely polished. On holding the ring in a vertical plane, after being carefully demagnetized, and bringing a paper of fine iron filings into contact with either of the polished portions of the edge, many of the particles were found to adhere, magnetically, and especially, as was anticipated, at the place of the joining. The adhering particles were more numerous and extended than in the former experiment; but I could not succeed in getting the iron ring to lift the smallest nail, or even minute bits of fine iron wire.

The feebleness of the magnetic attraction in a hoop or sphere of iron, it may be observed, compared with the energy of the same mass in the bar form, admits of easy explanation. The magnetic condition of a bar, as we have been led to view it, is that of a *battery* of magnetic particles; the particles, from the centre onwards, supporting and adding to the natural force due to the particles nearer the extremities, so as to concentrate the *ultimate power* in the extremities, as poles. But in the circularly, or spherically, cast mass of iron, in which there is no special terminus to the accumulating forces, the poles cannot be other-

wise than broad and diffuse bands or discs. Whilst, therefore, such centres of magnetism may be very powerful in their action on the proximate compass needle, the lifting power, which needs to be concentrated in an edge or extremity, is necessarily diffuse and feeble.

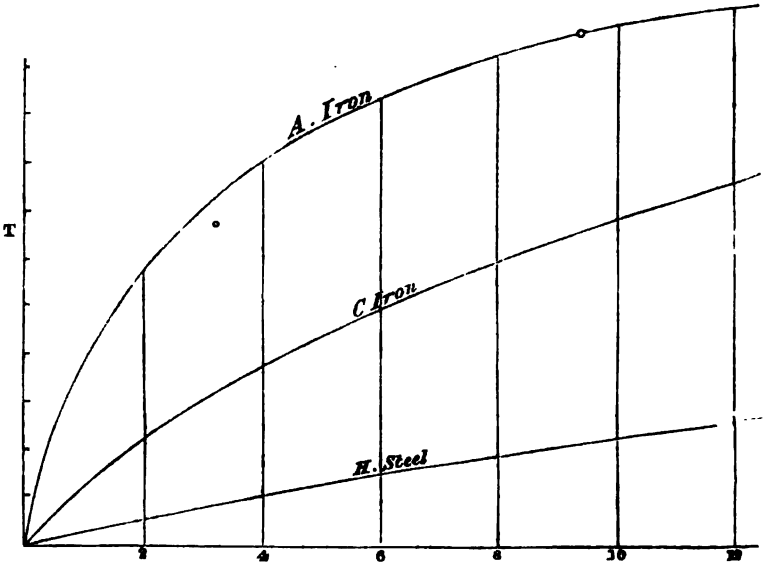
Seeing, then, that the body magnetized inductively by the earth, has all the properties characteristic of the true magnet; such as those of attracting or repelling either pole of the compass —of adjusting itself, when duly suspended, in the line of the magnetic meridian—of obeying the action of an iron bar similarly magnetized, or of an ordinary magnet, in the proper order of their respective polarities—and of communicating, as Coulomb had shown, permanent magnetism to bars of steel duly prepared for its reception and retention,—we may fairly, I think, conclude that such body is, actually and essentially, a *true magnet.*

One difference, indeed, there is, as to the *quality of retentiveness* of the magnetic power, which we have already noticed. In the permanent magnet, as has been remarked, the power, which in reality is adverse to the molecular tendencies, is sustained by the rigidity, in respect to magnetic changes, of the metal or ore. In the other it is sustained only by the inducing power, whilst the circumstances, as to their respective positions, are unchanged.

RESULTS.

THE annexed diagram, in which the deviations experimentally determined, of iron plates, crude and annealed, and hard steel plates in various measures of combination, are cast into curves proximately indicated, will serve at once to render the effect of mass and combination perceptible to the eye, and to yield more complete materials for a series of general results on the inductive influence of terrestrial magnetism.

FIG. 10.



The deviations, given in the tables I. and V., are here projected according to the respective proportions of the number and weight of the plates combined, as abscisses, and the tangents of the angles of deviation, as ordinates. The figures on the line of abscisses are indicative of the number of sheet-iron plates combined, and the marks on the line of tangents, T, shew the scale from which the ordinates are laid down. The upper curve, *A. iron*, is indicative of the magnetic powers, terrestrially induced, of the *annealed iron plates; C. iron*, of the powers of the same plates in the *crude*, or unannealed, state; and *H. steel*, of the combinations of *hard steel* plates in the relation, not of numbers, but of weight. The marks o, indicate the comparative effects of terrestrial magnetism on single plates or bars of annealed iron.

It will be remembered that all these bars and plates were of the same length, about 15 inches, and were all tested, as to the measure of magnetic energy induced from the earth, when placed in an upright position in the line of the east and west points of the compass, and at the distance of six inches *west* of the centre of the needle; that each angle of deviation noted in the tables was the mean, in most cases, of several trials, and, in all cases, the mean of the two ends of the plate or bar, as successively placed downward; that

the level of the lower end of the bar or plate, when tested, was about half an inch below that of the compass needle; and that, previous to the observation of the deviating power, each plate or bar was either accurately demagnetized, or any slight retention of magnetism therein allowed for in registering the observation.

1. That the general action of terrestrial induction is to develop in all bodies susceptible of magnetism, a magnetical condition; such bodies having properties corresponding in nature and influence, in their relative measure, with those of the developing agent, and, being for the time, real magnets.

A body terrestrially magnetized, possesses, as is shown in the foregoing researches, all the properties of a true magnet. It acts attractively or repulsively on the poles of a compass-needle—it conforms itself, if in fitting form and under proper suspension, into parallelism of direction with the magnetic meridian of the earth—it develops polarity in contiguous portions of iron, and attracts the iron so magnetized—in the same manner and under the same laws as any real magnet.

2. That the direction of the polarity and position of the poles developed, have always relation to those of the earth's magnetism—a neutral plane passing, in masses of uniform quality and temper, obliquely through, or near to, the centre of

gravity, in parallelism with a plane at right angles to the dip, with southern polarity above this plane, and northern below it.

This proposition was derived in substance from researches on the inductive influence of terrestrial magnetism on the iron in ships, made, originally, in the years 1825—1828, and the results published in 1829. What was lacking in the strict determination, experimentally, of all the elements of the proposition, was well supplied by Professor Barlow's contemporaneous researches.

3. That in spherically, or other regularly, formed bulky masses, the magnetic axis coincides generally (in the former case *strictly*) with that of the earth, the chief energy being at the extremities of such magnetic axis, and the neutral plane at right angles to the axis, in the middle; but that in bars, or tubes, or other elongated forms, the direction of the chief magnetic forces follows the course of the longitudinal extent of the bars, whatever be their direction, (except when in the plane of the magnetic equator,) exhibiting the two polarities, in maximum degree, at the opposite ends of the bars, with a neutral place in the middle.

Professor Barlow's elaborate and admirable investigations on the effects of terrestrially induced magnetism in the spherical form of iron shot and shells (as well as in some other bulky masses) have quite exhausted

that particular field of research; but not so as to the theoretical and general conclusions drawn from these investigations, with some of which the conclusions arrived at by personal researches are quite at variance. And, in regard to bars and other elongated forms, as has already been shown, the results heretofore obtained did not, as far as I am aware, embrace the general subject, nor serve to develop general laws, but only developed the phenomena of induction in a few particular or special cases.

The effects of *inclination* from parallelism with the earth's magnetic axis, in the case of iron bars, on the varying degrees of magnetism developed, have been largely investigated; but as the experiments belong to the enquiries of a subsequent part of this work, the special results are more conveniently reserved for insertion in their proper place.

4. That the *capacity*, or *receptive capability*, for magnetism terrestrially induced in iron, steel and iron ores, differs in the various kinds, and varies, in regard to the relative powers, with any change in their relative masses or proportions.

The highest capacity for magnetism, however developed, is found in malleable iron of the purest and softest description, and the lowest in ordinary iron ores and hard cast steel. But no particular ratio of comparative powers can be stated, except for special cases as to mass, figure, and proportions.

5. That, hence, the *proportional magnetic powers* of *different descriptions of iron and steel*, as determined for a particular series of equal and

given dimensions, will not serve as the general ratio for the different qualities, when the proportional dimensions of the masses (in another equal series compared) are changed.

This general proposition is very well elucidated by the examples of comparative powers projected in the diagram. For whatever ordinate we may happen to take for a comparison of the magnetic development in hard steel, annealed and unannealed sheet iron, will obviously yield a ratio peculiar to itself, and different from that of any other ordinate, whether pertaining to a greater or lesser extent of combination of the thin plates.

The law thus elucidated, with reference to combinations of thin plates for the increase of the mass, is the same, essentially, where the different bars compared are composed of solid masses.

Hence the differences of the ratios obtained by different experimentalists of the magnetic powers of the several kinds of ferruginous substances. The ratio, for instance, obtained by Mr. Barlow for malleable iron and hard cast steel, is stated at 100 to 49; but this, it will be obvious, applies only to the *particular case*, as to form, dimensions, and mass, investigated,—viz. the relation of equal bars of nine inches long, by seven-eighths of an inch square. For, from my own researches on the relative powers of equal and corresponding plates, or combinations of plates, of malleable iron and of hard cast steel, it was found, that whilst in the comparison of *single plates*, 15 inches in length and weighing 1246 grains, the ratio of the iron to the steel (the power of the latter being corrected for a small difference in weight) was as 100 to 9,—in

the comparison of a combination of plates of about 12,500 grains weight, the ratio was changed to 100 to 21; and where weights of 53,400 grains were compared, the ratio became as 100 to 38. [Deduced from the results in tables I. and V.]

6. That the power elicited in *any particular kind or denomination* of ferruginous metal, varies, in degree, with the temper or hardness and mass, and also, in equal masses, with changes in the hardness, temperature, form, and proportions.

The effects of *temper*, in crude and annealed malleable iron, are particularly conspicuous in the curves *A* and *C* in the diagram, representing the comparative deviations produced, in the two conditions of temper, by the series of plates and bars of table I.; where, for illustration, the magnetic power of a single plate was increased in the ratio of 100 to 313, by the mere softening influence of a red heat.

The illustration of the effects of form, proportions, and mass, belong to a subsequent result.

The influence of *temperature* on the capacity of iron for induced magnetism, does not come within the scope of the researches of this chapter; for as no perceptible difference was to be expected within the limited range of the temperature of the room in which my experiments were made, the consideration of the general subject was reserved for illustration to a future place, where the influence of heat incidentally applies. As, however, the advance in capacity is so very considerable at high temperatures, (as I found in experiments made in the year 1820,) the investigation of the ratio of capacity with temperature, I was led to

suppose, might not be altogether devoid of interest, nor did it, on trial, disappoint the expectation of eliciting some useful result.

7. That the *sustaining power*, or strength for eliciting high degrees of magnetic energy under terrestrial induction, *in different kinds* of iron and steel, is ordinarily the converse of the *receptive* susceptibility; so that the qualities of metal adapted for receiving magnetism most freely and energetically in thin plates or slender bars, are adverse to the accumulating of high degrees of power in ponderous masses.

This proposition, as to its general tendency, has obvious verification in the comparison of the curves of hard cast steel and annealed iron, in the foregoing diagram.

8. That the differences of sustaining power and receptive capacity in iron of diverse qualities, may yield, at certain points, as to the enlargement of the mass, in bars or combinations of any specified length, an equalization of magnetic energy.

Thus, in the comparison, again, of hard steel and malleable iron, where the capacity of the former is comparatively small and its sustaining power great, the inferiority of the steel in magnetic energy terrestrially induced, in the case of thin small masses, is seen by inspection of their respective curves in the diagram gradually to diminish, so as to indicate in their apparent direction, that if sufficiently extended

they might possibly ultimately meet and intersect each other. In such case, the abscyss belonging to the place of intersection would, for the specified length of the bar or combination of plates, determine a mass or weight of metal, in which the magnetic power of the hard steel and malleable iron would be equal; and beyond such mass the magnetic power of the steel, in the outset so inferior, would be expected to predominate.

In the comparison of the powers of crude and annealed iron, the tendency of their respective curves to meet is, even in our small combination of about a dozen plates, very observable.

9. That somewhat higher magnetical powers are developed in fasciculæ of plates or thin bars of iron, by terrestrial action, than in solid masses of corresponding form and general dimensions; and that a spreading out of the *surface* is generally favourable to the development of power.

This is a general law of magnetics, applying not merely to the transient effects of terrestrial or other induction, but to the condition of permanent steel magnets.

The general effect of surface, however, is but very small compared with that of mass, in all elongated forms, and hardly perceptible in long slender rods, but becomes highly influential (as elsewhere shown) in thick and ponderous masses.

10. That in the *combination* of similar iron or steel plates, or in equal additions to the massiveness of bars, (the plates and bars being of equal

lengths, and of the same quality and temper of metal,) the absolute gain of power, by the same modicum of mass, *progressively diminishes.*

This law is well illustrated by the curves in the diagram, and by the results in tables I. and V. Thus whilst an addition of two plates of iron (table I. col. vii.) to the first couple, augmented the power in the ratio of 100 to 157, two similar plates added to the fourth couple, previously combined, only produced an augmentation in the ratio of 100 to 106.

11. That the diminished effectiveness of corresponding additions to the mass, in solid bars or combinations of bars or plates, is the most rapid in the purest annealed iron, and the least so in hardest cast steel.

Tables I. and V., and the diagram (curves *A.* and *H.*), exhibit, to a limited extent, the extreme cases, in which the difference of effectiveness of equal augmentations to the mass is the greatest.

12. That whilst the effectiveness of additions to the mass in bars or elongated forms of iron or steel, continually diminishes, there is, probably, some measure of increase of power with the mass up to the magnitude of a cubic form, or of that of a cylinder or prism of a diameter equal to its height.

From the gradual approach of the curve to parallelism with the line of abscisses, in the projection of the powers of very massive combinations of bars, after the

form of the preceding diagram, I was at first led to infer that a maximum power might, in the progress of combination, be found, so as to render further additions perfectly ineffective. But this position, I ultimately ascertained was untenable, because the increase of *bulk* and *extension of surface* were conditions favourable to the development, or *sustaining*, of increase of power.

13. That the actual condition, as to degree of magnetic energy, of a mass of iron under the action of terrestrial induction, appears to be the result of two directly antagonistic forces,—the developing force derived from the earth, and the tendency of the molecular magnetisms of the metal to a state of neutrality.

It was formerly shown, chap. viii. part I, p. 146, part II, etc., that, as the magnetic arrangement or condition was one of tension, a reactive influence, tending to neutralize the polarities, reduces the energy of the ferruginous metal to a medium betwixt its actual capacity for magnetism, and this inherent tendency to a neutral condition. Hence, as the tension increases with the magnetic energy, and that energy, if duly sustained, would be proportional to the mass,—the enlargement of the mass, where the sustaining power is essentially deficient, is always attended with a comparative, and increasingly proportional, loss of power.

The lines, being curvilinear, which represent the relative magnetic powers of various combinations of plates of iron and steel, sufficiently indicate the general character of this reactive influence.

Hence, in *permanent magnets*, as well as in iron terrestrially magnetized, the stationary condition in energy is found to be the resultant of two antagonistic forces —that of the developing power as sustained by the rigidity of the metal or ore, and that of the molecular repellancy tending to neutralisation.

14. That these antagonistic forces have different ratios in respect of intensity; the terrestrial influence being, in its operation on iron of the same quality and condition, proportional to the mass acted upon, but the molecular tendency to the neutral state acting with a force progressively increasing with the increase of the magnetic tension.

This result of terrestrial induction, is a general law of magnetism as developed in iron and steel. It is sufficiently indicated in the results obtained by the combination of magnetic steel-plates, chapter I. of part II., and, correspondingly, in the effects of terrestrial influence on thin iron plates, section III. of this present chapter. Thus, whilst each of the series of annealed iron-plates, table I., derived, on an average, a power from the earth's magnetism producing a deviation in the compass-needle of 4° 4′ (tangent 71), the power of two such plates, compactly combined, was reduced from the amounts taken separately of 4° 4′ + 4° 4′, or 141 (the tangents of the angle of deflection) to tangent 102; four plates in combination, from 284 to 159; and ten such plates, from 711 to 220, indicating, in this latter case, a reduction of energy under the antagonistic molecular influence of above two-thirds of their separate magnetisms.

15. That the varying action of the antagonistic forces is such, that iron of bulky forms receives very inferior polarity from terrestrial induction to elongated masses of equal weight; whilst hollow dumpy cylinders, or shells used in warfare, may, in comparison of solid cylinders, or cannon shot of similar metal and like external dimensions, have equal magnetic development.

By the inspection of columns iii. and ix., table III., taking for comparison the bars of 1·5 inches and 1 inch diameter of proximate weights, we obtain abundant confirmation of the first part of this proposition. For we here find an inch bar, for example, of 24 inches in length, and of 38,200 grains in weight, having a deviating power of 25° 25′, whilst a thicker bar of half the length, and 42,100 grains in weight, had only a power of 14° 52′.

The comparison, furthermore, of columns iv. and vii., as to experiment No. viii. of the same table, will go far towards the establishment (in respect to hollow and solid cylinders of the shortest lengths) of the second part of our general result.

16. That in the comparison of magnetic development in *tubes* of malleable iron of various lengths, with corresponding lengths of *solid bars* of equal external dimensions and of bars of equal weights,—the effects of the antagonistic forces are so various that, in very massive forms, the tubular iron may indicate a recipient magnetic capacity as great as the solid bar-iron of the like

external dimensions, and of several times its weight, whilst, in very elongated forms, the tubular kind, will have little or no higher degree of energy than that of solid bar-iron of corresponding length and weight.

This proposition, through every part of its extent, has ample verification, I think, in the experiments recorded in table III. The experiments of section iv., on the relation of surface and mass on the inductive capacity of iron, likewise fully sustain the concluding clause of the proposition.

17. That hence it follows, that results of magnetic powers in any kind or quality of iron or steel, derived from experiments on a particular form or proportion of dimensions, apply only to that particular case, and become fallacious if taken for the determination of any general law, even for that special quality of metal; for, as a particular case, the magnetic power in spheres or dumpy cylinders or other massive forms, may seem to be according to *surface* rather than mass; whilst in slender or elongated bars it has clearly relation to *mass*, with but little comparative influence from extension of surface.

18. That the degree of *massiveness*, M, of any bar of iron, may be conveniently expressed by the square root of the area of the end or base divided by the length (page 77)—where a hollow tube

of moderate thickness of the massiveness $\frac{1}{c}$ or $\frac{1}{2c}$ may equal, nearly, in magnetic power, a solid block of metal of the same size and form; and where a tube elongated, as to massiveness, to $\frac{1}{16c}$ or $\frac{1}{20c}$ or beyond such elongation, may have little or no more power than a solid bar of equal length and weight.

This result of the varying effect of massiveness applies, though not in equality of proportions, to ferruginous bodies, generally, when in the magnetic condition. Hence, in the experiments of Sir W. Snow Harris, "On Induced and other Magnetic Forces," *hollow* cylindrical magnets (of massive forms we presume) were found as susceptible of magnetic power as *solid* masses of the same temperament and dimensions,"—a law apparently corresponding with that deduced from the experiments of Mr. Barlow and Captain Kator, but only, I am confident, of limited and special application; for my own researches (belonging to a different part of this work), where tubular magnets of elongated dimensions of steel are compared with solid bars of corresponding external dimensions, point to a totally different conclusion.

19. That the magnetism terrestrially induced becomes, like that in permanent magnets, so highly concentrated at the extremities of elongated bars or plates of malleable iron, as to yield an *attractive* power sufficient to lift small portions of iron, like a feeble magnet, and a *directive*

power adequate to a correct adjustment of position, in a plate duly suspended, like the needle of the compass.

These characteristic indications of iron terrestrially magnetized being a true magnet, are clearly elicited in the experiments 10, 11, 12, and in the satisfactory performance of the iron meridional needle, No. 13, of section viii.

CHAPTER III.

ON THE EFFECTS OF PERCUSSION, BENDING, FRICTION, AND OTHER MECHANICAL ACTION, ETC., IN AIDING, MODIFYING, AND NEUTRALIZING THE INDUCTIVE INFLUENCE OF THE EARTH'S MAGNETISM.

SECT. I.—*Historical Sketch of Researches (chiefly original) in this Department of Magnetical Science.*

DR. GILBERT, under whose truly scientific investigations magnetism first assumed the character and importance of a *science*, discovered, so early as the year 1600, that iron became sensibly magnetic on being hammered and drawn out on the anvil, whilst lying in a north and south direction. He made interesting experiments on the effects of heat, also, in destroying magnetism. Dr. Hook, in 1684, pursued very extensively this system of investigation, in respect to the action of *heat*, in developing the magnetic condition in bars of iron and steel. I am not aware, however, that either Dr. Gilbert, or any other experimentalist, (previous to the publication of the facts constituting the basis of the Investigations belonging to the present chapter,) obtained any

magnetical results from mere mechanical violence, independent of heat, or any actual *lifting power* by the processes referred to.

As experiments, however, by foreign philosophers, on the magnetizing or neutralizing effects of mechanical action, and on practical processes deduced therefrom, have not unfrequently been quoted in our native works on magnetical subjects, without reference to similar results which had been long, *previously*, before the British public,—it may not be deemed unfitting, I trust, to prefix to the matter of this chapter, some notice of the commencement and progress of my personal investigations on the subject.

My attention having been given (as elsewhere noticed) to the subject of the anomalies in the direction assumed by the magnetic needle, as observed on ship-board, during my voyages to the Greenland seas in 1815 and 1817,—I was guided to the conclusions constituting the substance of a paper on that subject, which was transmitted to Sir Joseph Banks, in 1818, and published in the Philosophical Transactions of the following year.*

The effect of terrestrial induction, as observed

* This paper, somewhat extended, was re-published in 1820, in the "Account of the Arctic Regions," vol. ii. pp. 537—554.

more particularly in iron having an *upright position* in the ship, and as modified or neutralized by changes in the position of iron bars, had led to the contrivance of an instrument (described summarily in the paper referred to) for determining the inclination of the magnetic needle by the observation of the *plane of no-attraction* in the direction of the magnetic meridian. In pursuing my enquiries with this instrument, in its original and imperfect form only, it occurred to me to try the influence of vibration and percussion in varying the effects produced. At first, indeed, though the effects proved very surprising, the differences and apparent discrepancies were very perplexing. But when the laws regulating these differences were elicited; then the results became as consistent as they were certain and beautiful. I well remember having received a visit from M. Clement, at Liverpool, whilst these investigations were in progress (it was in the winter I think of 1818—1819) when I showed him the leading effects of percussion in augmenting, reversing, and neutralizing the magnetism, according to changes in the position of a small bar of iron under the action of a hammer. Astonished with the suddenness, and characteristic nature, of the changes, he exclaimed, "Magique! magique!"

In the spring of 1820, a description of the

new instrument, by which the results shown to M. Clement were determined, was communicated to the Royal Society of Edinburgh; and in the following winter a more particular account of it was given in a paper entitled—"Description of a MAGNETIMETER, being a new Instrument for measuring magnetic attractions, and finding the dip of the needle; with an account of experiments made with it."*

This paper, which was forwarded to the secretary, Dr. Brewster, for the Royal Society, January 9th, 1821,—comprises descriptions of the general phenomena resulting from terrestrially-induced magnetism on small bars of iron and steel, as affected by changes of position, and as augmented, modified, or neutralized by *mechanical action*,—whether of hammering, scouring, filing, bending, etc.—as also by electrical discharges and currents. It likewise includes the important result, derived from experiments made before the close of 1820, that "*hot iron*, receives more magnetism of position than the same when cold." The increase of capacity, indeed, for terrestrially-induced magnetism, by heating an iron bar to redness was such as to raise its deflecting power on the needle of a small compass, 1·25 inches distant, from 27° 30′ (when cold) to

* Transactions of the Royal Society of Edinburgh, vol. ix. p. 243.

60°: and on another trial, at a shorter distance, from 15° to 77°!*

These enquiries being continued during the ensuing year, as my engagements in an adventurous profession afforded the requisite leisure, yielded the materials for a paper read before the Royal Society, March 7, 1822, and published in the Philosophical Transactions, vol. cxii. pp. 242—252. It is entitled, "Experiments and Observations on the Development of Magnetical Properties in Steel and Iron *by percussion*;" and comprises the researches made on the effects of this process when the small bars, subjected to it, rested on non-magnetic substances and on a rod of iron, with the application of the process to practical magnetics and particularly to the construction of magnets, without the use of any previously magnetized substance.

In the pursuance of these researches, so much new information was elicited as to afford materials for another communication, under the same title, to the Royal Society, by the hands of my kind friend, Sir Joseph Banks. It was forwarded in 1823, and obtained a place in the

* Professor Barlow's interesting investigations on this subject are comprised in the second edition of his "Essay on Magnetical Attractions," of the date Oct. 22, 1822, in the preface, and published in 1823. A notice of the results, however, I find in the Edinburgh Philosophical Journal for April 1822.

Society's Transactions of the year following. The method of percussion is therein described, in the employment of large and massive bars of iron, and as to the effects of the "compound process," or the hammering of steel wires or bars, *betwixt* two bars of iron, whilst the whole series is held upright in one straight line. This paper also comprises the result of difference of temper in the steel wires thus magnetized, with a variety of deductions on magnetic principles and phenomena.

And, finally, I may notice, with respect to this historical sketch, that the plan of magnetizing by percussion was carried out practically and most effectively in the year 1822. It was during a voyage to the Greenland whale-fishery in which this result was attained,—a voyage wherein I had the opportunity of determining, for the first time, the position of the eastern coast of Greenland from the 69th to the 74th degree of latitude, and of making, I trust I may say, a no inconsiderable contribution to the geography of this interesting, and till then all but unknown, region. Nine pieces of a common steel-bar were, on the occasion referred to, bent into the horse-shoe form by the ship's armourer, roughly and imperfectly tempered, and then magnetized by the new process, (there being no magnet, except compass needles, on board,) when a lifting power

of 18 pounds was obtained, after three series of manipulations, on the very first experiment.* Subsequently, employing only the original magnetism as the developing agency, the permanent lifting power was raised to 30 pounds, and, finally, after a better tempering of the bars, to about 85 pounds!

SECT. II.— *On the Development of Magnetism in Iron by percussion, with Definitions illustrated by rudimentary Experiments.*

THOUGH the original investigations on this branch of magnetical science are of such distant date, and, as shown in the preceding historical sketch, have been so long before the public; yet it is needful, in order to the due intelligibleness of additional results and completeness of the series, that the leading experiments and facts should now be combined. No further apology, therefore, will I trust be deemed necessary, for again taking up the earlier facts and experiments, as scatterred through the transactions of different learned societies, or scientific journals, nor for now commencing with the description of the rudimentary experiments out of which the results subsequently determined successively flowed.

* "Voyage to Greenland, in 1822," pp. 56—60.

For eliciting the various and striking effects of mechanical action, and, in the first instance, the effects of *percussion* in the development of the latent magnetisms in malleable iron,—any iron bar of convenient length, say three to four feet, may be employed. But nothing answers the purpose better than a substantial *kitchen poker*. Instead, therefore, of referring back to the exact form of the experiment belonging to the original investigations, I select now a series specially conducted with an instrument of this kind, which may at once serve to elucidate the principles whereon the varieties of the phenomena are dependent, and to afford characteristic facts for a series of *definitions* (for aiding and simplifying future descriptive records) pertaining to the various qualities, in respect to evanescence and fixidity, of the magnetic condition in ferruginous bodies.

The entire apparatus, for these rudimentary experiments, consisted of a substantial soft iron poker of about three feet in length, a small pocket-compass having a naked needle, and an ordinary small hammer. The compass, placed with its centre six inches from the edge of a table, and on the side to which its needle was parallel, was adjusted with its north and south divisions, as determined by the coincidence of the needle, in the line of the magnetic meridian.

The magnetic condition of the poker, under the various changes produced by percussion, was, under this arrangement, easily and satisfactorily determined, by bringing its knob end against the side of the table, whilst it was held horizontally in an east or west line from the compass, and observing the angles of deviation produced in the compass needle—the tangents of these deviations yielding the relative measures of the magnetic force exerted by the poker. The following, commencing with a trial of the deviating power of the non-magnetic poker as induced by position only, (after the manner of experiment No. 2, page 14, and figure 1, page 17,) comprises the series of illustrative experiments.

[15. *Exp.*]—The existing magnetism of the poker was first accurately neutralized (by the process described in case 1, sect. iii., chap. vi.), so that, when either of its ends was presented to the compass in the horizontal position, west from the compass, there was no sensible action. But being now placed upright, point upwards, with the *knob* at the edge of the table (or six inches from the compass) the north pole of the needle was repelled to the extent of an angle of 21°. Held in the direction of the dipping-needle, the deviation was increased to about 22°. The experiment repeated with the *point* of the poker

presented to the compass produced very nearly corresponding effects. This *quality* of magnetism, being due solely to *position*, of course disappeared (or very nearly so) on the poker being presented in the *testing position*, the horizontal, in the line of east and west.

[16. *Exp.*]—A smart blow of the hammer on the square side of the lower end of the poker whilst it was held (otherwise unsupported) in the hand in a *vertical* position, increased the *upright* deflecting power of the knob from 21° to 35°. Six more smart blows, given in a similar manner, and whilst held in the same position, yielded a deflecting power in the *upright position* of 44°, and in the direction of the dipping-needle of 46°. Presented to the compass whilst held horizontally, the deflecting power *retained*, after one blow was found to be 15°, and after the seven blows 26°. Thus whilst terrestrially-induced magnetism yielded a power, in the direction of the dipping-needle, of 22°; the percussion from seven blows gave a power of 46°. Or, comparing the powers at the proper testing position of the plane of the magnetic equator, we find an increase from the neutral to 26°.

[17. *Exp.*]—The poker being *inverted* in respect to the position in which its magnetism had

been before developed, was again struck, when a single blow was found not merely to have neutralized, but to have *changed the poles* to an extent of 19° of deviating power, and six more blows up to 27°, as tested in the horizontal equatorial position.

[18. *Exp.*]—The poker, thus highly magnetized, was struck a single blow whilst held in a horizontal position (east and west) which reduced the deviating power in the testing plane to 3°, and six more blows to 1°.

[19. *Exp.*]—The poker magnetized as in experiment 16, whilst held upright, to a deflecting power (tested horizontally) of 26°, had its power augmented by six blows, whilst it was held in the direction of the dipping-needle, to 29°, which was *reduced*, however, by half-a-dozen blows, struck when it was held again upright, to 27°. Inclined at an angle of 40° from the vertical, with the upper end directed southward, (being in this case no further from the magnetic axis than when held upright,) the former deviation was retained whilst the poker was hammered.

Hence we find the theory of the terrestrial action, in respect of position, strikingly supported by these characteristic facts—a *gain* of power on that elicited by the vertical hammering, by ham-

mering in the direction of the earth's magnetic axis; and a subsequent *loss* of power by hammering again in the direction of the plumb-line.

Now from these several experimental facts, which will be found to be characteristically illustrative of varieties in the nature or quality of the development of magnetism in iron substances—we may deduce a series of DEFINITIONS, which I here venture to submit, as conveniently descriptive, I conceive, of the varying qualities in respect to evanescence on the one part, and measure of stability on the other, of the magnetic condition.

1. *Magnetism of position, or terrestrially-induced Magnetism.*—The simple and spontaneous effect of terrestrial influence on iron in a neutral state, or devoid of magnetism in any degree fixed, which changes, as to its poles and neutral plane, whenever the position of the mass of iron is changed, in conformity or parallelism with the axis and equatorial plane of terrestrial magnetism. Of this quality of magnetism, experiment No. 15 is characteristically illustrative.

2. *Retentive Magnetism.*—The excess beyond, or augmentation of, the magnetism simply developed by terrestrial influence. This condition, which is readily elicited by percussion,

or other mechanical, as well as chemical, action, remains, in considerable degree of energy, under all changes, *quietly* effected, in the position of the iron. It is aptly exhibited in experiment No. 16.

The characteristic difference betwixt the *retentive* quality, and that of *permanent* magnetism, appears in experiment No. 17, where the retentive quality is seen to be liable to change or neutralization on a repetition of mechanical violence under diverse circumstances of position, whilst on permanent magnets the same treatment produces no change of polarity, and but comparatively small effect on the original intensity.

3. *Magnetism terrestrially sustained.*—The magnetism, whether simply induced or retentive, which abides, with very moderate alterations, (whilst congenial in polarity, to the earth's sustaining influence,) under all kinds of mechanical violence, and even under changes of position, *within* certain limits, as to the inclination of the poles of the iron body with the terrestrial magnetic axis. This quality it is, which gives the effect of permanent magnetism to the vertically acting magnetism of iron-built ships, whilst navigating within limited differences of the magnetic latitude in which they may have been originally built, or in which they may have been

long subject to the vibrating action of the steam-engine, or the mechanical straining from the encountering of heavy seas. This quality is characteristically illustrated by the experiment No. 19, where additional blows in very different positions of the bar are found to produce only a slight change in the quantity of magnetic force; the general magnetical development being terrestrially sustained.

4. *Permanent or fixed Magnetism.* — This quality, not indeed illustrated by the experiments on the iron bar, is strictly that which characterises all permanent magnets,—whether endued with this property naturally, as in the loadstone, or artificially, as in magnets constructed of hardened steel, or of hard cast-iron,*—in which the energy, for the most part, remains with but little diminution, under any ordinary species of mechanical action, however long or violently applied.

* As to the capacity of cast-iron when *cast hard*, for permanent magnetism, the researches described in part II. chapter VIII., are sufficiently demonstrative. Subsequently to the publication of part II. (in 1845-6), I obtained *iron castings*, adapted for the bars of a compound horse-shoe magnet. The attractive energy of the bars was such (some of them lifting a weight of 15 lbs.) as to result, under combination, in the production of a magnet of very considerable and effective powers.

In the original Investigations on the class of phenomena of which we have just given some of the most characteristic illustrations,—the effects of percussion on iron bars were extensively examined, as to any modification of the results in respect to the *sort* of hammer employed, the *direction* in which the blows might be given, or the *part* of the bar on which they might be struck. But it was found, as to the sort of instrument employed, that a hammer of brass, or percussion with a stone, or a blow by the iron itself, on a hard substance, produced corresponding effects, provided the blows were equally sharp and powerful; that the *direction* in which the blow might be given, whether upward, downward, sideways, or obliquely, had no observable effect on the result; and that the part of the bar struck, whether the upper or lower end, or any part of its length, seemed not, in any way, to alter either the efficacy of the process or the measure of the influence produced. The only circumstances, therefore, of real importance, as affecting the results in any particular bar of iron, were, the *direction*, in reference to the earth's magnetic axis, in which the bar was held whilst being hammered, and the force, smartness, and number of the blows that might be struck, or, in other words, the *quantity of percussive action.*

Such is the effectiveness of this species of

mechanical action in controlling the incidentally developed magnetisms of malleable iron, that I have never yet met with a poker, or other bar of soft iron, which had rigidity sufficient to resist the neutralizing or changing influence of position and percussion. Any of the most strongly magnetic pokers, I happen to have tried, would, on reception of a few blows of a hammer with the point upward, be found to have lost its former magnetism, or, more usually, to have had its polarity entirely reversed.

Though the experiments, hitherto described, have been confined to the action of percussion on but one form of iron, that of *bars* or *rods;* yet the same principles, it may be remarked, apply, differing only in degree of effectiveness, *generally*. For no kind or form of malleable iron, which I have hitherto met with and tested, —however thin or extended on the one part, or thick and massive on the other, having received a magnetic condition from mechanical violence, or the operation of time, in connection with position,—has proved insensible to analogous influences. Plate or sheet iron, for example, as hereafter shown, conforms to the same laws, and elicits, under the hammer, or under any other form of vibration and violence, corresponding magnetic changes.

The experiments we have selected for the illustration, magnetically, of the effects of percussion on iron bars, were special and particular, in order to their better applicability to our definitions of the different *qualities* of magnetism; in their essential bearing, however, it is hardly needful to say, they may serve, suggestively, for general guidance as scientific recreations. In this application, we may submit to the experimentalist a modification of one of the cases described, which seldom fails to interest and surprise those who witness the phenomenon. The apparatus required is similar to that already described, viz., a small *lively* compass, with a naked needle of one to two inches in length, a common hammer, and a poker of almost any kind, though one of *iron* answers best. The experiment, descriptively given, is as follows:—

[20. *Exp.*]— Place the compass about three inches from the edge of a table, (on the east or west side of it,) and adjust its needle to the zero of the graduation. Holding the poker, designed for the experiment, with its *point upward*, strike it with the hammer, smartly, a few blows on the square part, or on the point. Turning it now *point downward*, and holding it upright, with its knob end against the edge of the table, proximate to the compass, whilst its point is *on* or near the floor,—

observe the action of the poker on the needle, which, if the hammering has been moderately sufficient, will probably be very weak, if not quite inert. For an inert condition of the *knob end* is here expected, on the presumption that such a degree of *northern* polarity will have been developed by the percussion in the former position, as to balance or compensate for the tendency of terrestrial induction to produce, in the change of position, *southern* polarity. If the action, however, of the knob, as now situated, be to *attract*, in any considerable degree, the north pole of the compass, the hammering, *point upward*, must be repeated until this tendency ceases. If the knob end, on the other hand, whilst held upward, should *repel* the north end of the needle, (which can only happen in a moderate degree,) it will indicate somewhat of excess of the reverse polarity; but an excess is favourable, rather than otherwise, to the effectiveness of the experiment.

Whilst now the poker is supported on the floor, or held up (if too short for the height of the table) till its knob is on the level of the compass,—let a smart blow be struck on the top of it, and instantly, by virtue of the change in its polarities, the needle will start aside, or whirl round (the north end attracted by the poker), as if acted upon by some magical power. The effect, where the previous reversing of the polarity in the poker,

and the steady adjustment of the needle, have been properly managed, can hardly fail to surprise and delight an intelligent company or enquiring investigator.

SECT. III. — *On the Effects of Percussion in developing and changing the Magnetical Polarities in Bars of soft Steel.*

SOFT STEEL, though less susceptible of the action of percussion than malleable iron, is, nevertheless, subject to analogous influences.

Two bars, one of best cast-steel, the other of shear-steel, and just in the condition in which they came from the tilt hammer of Messrs. Sanderson and Co., were subjected to experiment for the rough examination of their susceptibility of magnetic influence from this process. Each bar was sixteen inches long and half an inch square.

The *cast-steel* bar, on being placed for trial on the deviation-board, at six inches distance from the compass, was found to possess (probably from the action of some bar magnets with which it had been packed) a degree of polarity producing a deviation by the marked end of 7° E. Having struck a dozen smart blows with the marked end up—a position adverse to its existing magnetism and therefore calculated, under percussion, to

change its polarity—its deviating power was found to be reduced to 5° E. Twenty more blows left only a power of 3° E. And above a hundred more, some struck on the upper end and some on the sides of the bar, just served to destroy the magnetism; whilst fifty more, struck in like manner, left it still neutral.

When the influence of this species of percussion had thus been brought to a maximum, with the marked end of the bar upward, a few blows (about twenty) were struck with the *reverse* end upward, the effect of which was to restore the original polarity to the extent of a deviation of 6° E. Thirty additional blows put it exactly into its original condition.

On testing the bar of *shear-steel*, as to any existing polarity, the marked end (a *north* pole) was found to possess a deviating power of 8° easterly.

Thirty blows, with the marked end upward, totally reduced the magnetism, with an inclination somewhat westerly. Sixty more blows, some on the upper or marked end, and some on the sides, gave a deviation of 3° W., which was not increased by additional hammering.

The bar being now struck ten blows, whilst held in a *horizontal* position and in the magnetic line of east and west, had its original magnetism partially restored—to an extent, at least, of a

deviating action of 1° easterly. And ten more blows, when the marked end was *downward*, restored the original condition to an extent of 6° E.

The laws, therefore, which in their operation are so influential under percussion in regard to malleable iron, were thus shown to have effect, though in an inferior degree, in respect to untempered steel. The bars, however, having been considerably hardened by the compression of the tilt hammer, exhibited a less effectiveness from percussion than would, no doubt, have taken place had they been softened by annealing in the fire. But as the object of the trial had been sufficiently gained by the experiment described, it was not thought necessary, in this particular connection, to pursue the enquiry further.

So far as the experiments were pursued, the general phenomena were exactly in accordance with what had been anticipated. The shear-steel was more readily and extensively affected by the percussion than the cast-steel; and the effect of percussion, which had been feeble in its result towards *inverting* the incidentally acquired magnetism, was (consistently with the deductions from my original experiments described in the Philosophical Transactions for 1824) sudden and influential in restoring, by the favourable change of position in the bar, the primary polarity.

SECT. IV.—*On the Development of Magnetical Polarity in malleable Iron by bending, twisting, or other mechanical flexure, or vibratory action.*

ALL the phenomena to which we have just referred, as the results of percussion operating in aid of terrestrial induction, are likewise (as shown by my earliest investigations *) derivable from mechanical flexure, or vibratory action. This correspondency of results, as well as the effectiveness of the several operations, is remarkably evinced in the *bending* or *twisting* of bars or plates of iron.

Hence, just as we have seen the effects of percussion, in yielding a considerable polarity in bars of iron, and in reversing or neutralizing such polarity in accordance with the *laws of position;* so are the effects, in relation to the position in which the iron may be held, and in correspondency of energy, of bending or twisting in similar masses.

And, as in the case of hammering, the several effects take place, mainly with reference to position as to quality, and to violence as to quantity; so, in the case of these other operations, the results are chiefly influenced by the same circum-

* Transactions of the Royal Society of Edinburgh for 1821, and Philosophical Transactions for 1822 and 1824.

stances, having but little relation to the part or place in the rod or sheet of iron to which the violence may be applied.

A bar, wire, or plate of soft iron, acquires a considerable degree of polarity, if thus treated whilst held in an upright or proximate position; has its polarity reversed by the repetition of the process in the inverted position; and has its condition demagnetized by an additional twist or bend being made whilst it is placed in the plane of the magnetic equator.

The operation, to be *the most effective*, should proceed to the extent of an actual change of form, leaving, for instance, a slight bend or twist in the metal acted upon; but it is in no slight degree influential even when acting only within such extent of the elasticity of the iron as may serve fully to restore the original form.

In twisting a rod or wire of iron, the result has no regard to the *direction of the twist*, nor will the reversing of the twist, as some have supposed, at all serve to neutralize the former effect, without the appropriate change in the position of the wire. For an iron wire having been magnetized by twisting whilst held in an upright position, is found, in most cases, to have the *same* polarity more highly developed than before, by twisting in the contrary direction; but in no case is the power diminished by

this treatment, much less reversed in denomination.

So sensitive are the magnetical qualities of the iron to this operation, that a positive influence, from degrees of flexure scarcely discernable, may, by the action on a delicate compass, be detected.

Hence arose a considerable difficulty in the determination of the simple effects of terrestrial induction on the combinations or bundles of sheet-iron plates employed in some of the foregoing investigations. For so sensitive were these plates, I found, to the smallest flexure, that the bundle could scarely be lifted by the hand without vitiating, in some degree, the accuracy of the experiment. To guard against this disturbing influence, it was found necessary to tie up the bundle of plates, compactly and firmly, whilst they were supported in the plane of the magnetic equator; and then to lift them, whilst placing them upright on the deviation-board, by *the edges*, where the force of the fingers could produce no sensible compression.

For experiments in this department of magnetical phenomena, designed only for illustration or recreation, I may suggest, under much experience, the following forms as at once simple, effective, and surprising.

[21. *Exp.*]—Provide, for these experiments, two or three plates of thin sheet-iron; say, about eighteen inches in length, two in breadth, and, in substance, about the thickness of a shilling. Anneal them, by passing them through a clear fire so as to heat them to redness throughout, letting them cool gradually. They may then be tied up, laid flat on each other, compactly in strong paper, in which condition, whilst they can be handled without soiling the fingers, the results, from the invisibility of the magnetical agent, appear the more surprising. One end of the bundle of plates should be marked, for the purpose of descrimination. A small compass should also be provided and adjusted on any part of the surface of a steady table.

Previous to the exhibition of the experiments, if designed recreatively, neutralize the iron plates by a moderate flexure, without permanent bending, whilst held in the position of the east and west horizontal line. The plates then being laid flat on the table, for testing, within about three inches of the compass, and in the direction of its east or west point, should, if duly demagnetized, produce no deviation.

(*a*). Holding, now, the bundle of plates in an upright position, with the *marked end downward*, give it a moderate flexure both ways, when, presenting it to the compass, as just directed for the

testing, the marked end will be found to *repel* the north pole of the needle — probably, at three inches distance, to an extent of 25 or 30 degrees.

(*b*). Bend the plates, secondly, with the *marked end held upward*, and the polarity will be found to be reversed,—the marked end (the plates being laid flat on the table as before) now *attracting* the north pole of the compass, and to an extent, probably, as great as it was previously repellant.

(*c*). Holding the plates, thirdly, in *the horizontal position* of east and west, repeat the operation of bending, and, on trial again of the magnetic state, by the compass test as before, the polarity will be found to be pretty nearly neutral, or, if the experiment has been perfectly ordered, to have wholly disappeared.

(*d*). Striking the plates of iron against the hand, I may also remark, will be found to elicit, under the several varieties of position, the same phenomena. And there are few results, perhaps, derived from the operation of principles of this nature, calculated to excite more agreeable surprise and interest, than those of (what I would venture to designate) this elegant experiment.

[22. *Exp.*]—A modification of these effects of bending on plates of iron, may be exhibited

without such obvious changes of position, and in a manner calculated, therefore, though not producing such great deviations, to excite, perhaps, still more astonishment. We submit to the curious experimenter the following variety in the manipulations.

(*a*). With the compass adjusted as before, and the bundle of iron plates duly demagnetized, remove them, for the bending, from the table, and *keeping them still in the horizontal plane, direct the marked end towards the north*, and impress on the plates, whilst so held, the requisite degree of flexure, or strike them with the hand. This influence — impressed whilst the plates though horizontal, as to the earth, are inclined near 20 degrees to the plane of the *magnetic equator*,—will be found to have yielded, on reference to the usual compass test, northern polarity to the marked end of the plates sufficient for a distinct, if not for the considerable, repulsion of the north pole, or possibly, as I have myself realized, for a deflection to the extent of 10 to 15 degrees.

(*b*.) Repeating the bending, or strokes of the hand, with the plates now pointed with the *marked end towards the south* and held horizontally,— the polarity of that end will be found to be reversed.

(*c*). Finally, bending the plates once more

whilst held in the *east and west line*, horizontally, —the previously acquired polarity will be found to have vanished.

A *vibratory action*, in whatever manner produced, results, according to its measure of disturbance in the substance of the iron, in the development of phenomena, in exact conformity with those elicited by percussion or bending. Thus the vibrating of an iron bar whilst suspended, or held upright, in the hand, by a series of slight blows with any substance calculated to make it ring, is sufficient to develop in it a very considerable degree of magnetic energy; whilst a single blow with the fist, on a bar thus supported, may have the effect of neutralizing, if the position be duly adjusted, any slight polarity incidentally acquired by mechanical action with the contrary end upward.

In like manner scouring, filing, polishing, or any other process acting on the surface of a piece of iron or soft steel, has a corresponding magnetizing, or demagnetizing tendency, with reference to the position of the metal when thus operated on.

In these results we have an explanation—and, no doubt, a correct one—of the high magnetic condition, long ago observed, in certain bars of

iron which had been fixed in an upright position. The cases referred to belong to the history of magnetism. A surgeon of Rimoni, Julius Cæsar by name, in the year 1590, observed the conversion of iron into a magnet, in the case of an iron bar supporting a piece of brick-work on the top of a tower of the church of St. Augustin. A similar condition in an iron bar was observed by Gassendi, about 1630, which had been on the cross of the church of St. John at Aix, and had fallen down by the action of a stroke of lightning. In this case, too, the foot of the bar, which was much corroded, was found to possess the attractive properties of the loadstone.

These bars, it may be plainly inferred from their position, must have been perpetually subject, during high winds, to a vibratory action,—besides the shock which the latter must have received from the lightning,—a circumstance peculiarly calculated, especially when operating through a long series of years, to develop, in the highest degree in which such influence might be availing, the latent magnetisms of the iron masses.

Sect. V.—*On the Influence of Electrical Action in the Development of Polarity in Iron.*

Electricity, in the mode of its operation, seems to have a magnetizing influence on two distinct

principles of action,—the one arising out of the mutual sympathies, as peculiarly acting physical agents, of magnetism and electricity, and the other acting, apparently, only mechanically.

It is to the latter form of magnetical development, and by the action of *frictional* electricity only, to which my observations, in this section, have reference,—being a branch of enquiry which engaged my attention whilst pursuing the very first series of extended investigations on this curious subject.

It was then ascertained (in the year 1820) that an electrical discharge, made to pass through a bar of iron, void of magnetism, when placed anywhere near the direction of the magnetic axis of the earth, renders the bar magnetic,—the upper end becoming a south pole, and the lower end a north pole; that the polarity is reversed by a similar discharge with the bar inverted as to its position; and that, whilst a discharge on a *neutral* bar situated, as to direction, in the plane of the magnetic equator produces no magnetic development, a similar action on a bar which may have been magnetized by a like electrical discharge, tends to neutralize its polarity.

These effects, differing only in the *extent* of the influence, appeared to be the same, whether the bar received the discharge of only a single Leyden jar, or several discharges of a powerful

battery of sixteen jars;* nor by varying the direction of the discharge, by putting first the upper end of the bar in connection with the positive, and then with the negative quality of the battery, was any difference in the effect observable. The nature of the result was, in every case, referable to the position of the bar.

Similar magnetical effects, though only in a very inferior degree, are produced by the mere passing of a stream of electricity through a bar of iron; and in this case too the influences appear to be simply *mechanical*, since no difference is perceptible betwixt the action *upward*, or *downward*, of a corresponding current.

Sect. VI.—*On the Effects of Heat in increasing the Magnetical Powers of Iron as terrestrially developed.*

Reference has been made in section I. to experiments, undertaken above thirty years ago, on the influence of temperature in augmenting the magnetical development, in small bars of iron, under terrestrial induction. But these experiments were confined to a particular heat—that of a medium redness.

* In these original investigations on the effects of electrical discharges, I had the assistance of my friend Professor Traill with his excellent electrical apparatus.

Subsequently, and indeed very recently, the investigation was extended to the trial of the effects of *moderate degrees of temperature*, with the view, especially, of ascertaining, whether any appreciable differences might be produced within the range of the ordinary changes in the temperature of the atmosphere?

Not having the command of a convenient oven, which might have enabled me to subject bars of iron to an uniform and determinable temperature,—it occurred to me that I might attain the same object by means of hot water. For placing them, at their ordinary temperature, in a tubular vessel, and having ascertained their magnetical powers in an upright position, after the form of fig. 8, page 37, and then surrounding them with boiling water, I expected to be able to determine the magnetic change, if any, by reference to the compass deviations. Or still more simply, it seemed, my object might be effected, by means of the tinned-iron vessel employed in the researches of section IV. of the preceding chapter, which could easily be heated, and that with much uniformity, by filling it with boiling water whilst resting on the deviation-board, so as to enable me to detect the minutest change in its magnetical capacity. The first results obtained were so surprising, and subsequent variations so curious, that it may not be

uninteresting to give a particular record and description of the phenomena elicited.

The cylindrical vessel referred to, which was about 18 inches in length, and 2·5 inches in diameter, being placed upright on the deviation-board at the distance of about six inches from the compass, measured from centre to centre,—produced, at the temperature of 60°, a deflection of 4° 35′ E., on the north pole of the needle. Boiling water was then poured in from the spout of a tea-kettle till the vessel was nearly filled, when the deviation, to my much surprise, increased to 13° 35′, under a resulting temperature of 198°. On the vessel being emptied and allowed to cool down to its original temperature, the deviating action, upright, was still as high as 12° 15′, and, being laid horizontally in the east and west line, the residual or *retentive magnetism* was found to be 7° 40′.

The tube being again neutralized, by a few taps when held in the proper position with a bit of wood, was replaced on the deviation-board and filled with the same water. The resulting temperature was 132°, and the *increase* of deviating power extended from 4° 30′ to 10° 50′.

An increase of magnetic action to nearly treble the original amount by a change of temperature of only 138°, seemed to me so extraordinary that

I was led to suppose that the vibration produced in the vessel, by the fall of the stream of water, might have served to augment the simple effect of temperature. Guidance in this doubt, it seemed probable might be yielded, by filling the tube, as I subsequently did, whilst inclining it in the plane of the magnetic meridian, so as to bring it into the position, nearly, of the magnetic equator. As in this case, any magnetizing effect from vibration would be prevented, I supposed that the influence of temperature would alone be indicated. And, *apparently*, it was so; for on placing the tube, when filled, in its place on the deviation-board, I found, though the temperature was yet as high as 120°, that the magnetic action was only 4° 45′,—a quantity indicating but an extremely small increase. Hence it was inferred that the supposition was probably correct, that the great increase observed in the magnetic capacity of the vessel in the first experiment was due to the vibration produced by the stream of water, under a boiling temperature, whilst the minute augmentation, in the third experiment, of 10′ to 15′, was the sole effect of temperature.

Not satisfied, however, with the inference I had been almost compelled to draw from these experiments, I proceeded to test the effects of

temperature on a plan in which vibration, in the early stage of the process at least, would be entirely avoided.

Blackening the base of the tinned vessel for securing a better action in heating it, I placed it, when filled with cold water, over a spirit-lamp supported on a brass retort-holder,—raising the compass, for a due correspondence of level, as high as the base of the tube. The temperature, at the commencement, was 47°, and the deviating action of the tube (being previously neutralized) was 4° 30′. On lighting the lamp the magnetic action was found gradually to increase with the temperature, at the rate of about 10′ of deviation for each 20° of temperature, until at 202°, the highest, a total increase of 1° 16′ was observed.

This result, so inferior in magnetic augmentation to that produced by pouring boiling water into the vessel, again indicated the operation of some other cause than mere temperature,—such as that of vibration, to which I had been led to ascribe the development of the strong polarity elicited in the primary experiment.

But still unsatisfied with the conclusion to which the several experiments seemed to point, it fortunately occurred to me to try the effect, if any, of vibration from a stream of *cold water*, so as to separate altogether this particular action,

whatever it might be, from changes of temperature. The trial was quite conclusive in *disproving* the idea originally entertained of the cause of the phenomenon observed. For on neutralizing and replacing the tube in its original position on the deviation-board, and, after observing its action on the compass, pouring in cold water from the kettle,—I found that there was not only no increase of action, but, if any, a reduction of the power when empty!

It now became evident, that the trebling of the magnetic power in the tinned-iron vessel by the pouring in of boiling water, was not owing to the vibratory or percussive action of the stream of water; and it was equally evident that the phenomenon was not due to the *simple* action of heat, as a heat still greater, when derived from the spirit-lamp, did not produce above a seventh part of the effect of what resulted from the filling of the tube with boiling water.

The only other view of the phenomenon which the present state of our knowledge, concerning the nature of the mysterious agency under investigation, seemed to suggest, was to refer it to an effect of unequal heating, or, in other words, of *thermo-magnetism*. And this, I doubt not, is the true explanation of the great augmentation of magnetic energy produced by filling the tube with boiling water,—a process calculated to heat

the base of the vessel first, and to carry the higher temperature progressively upward.

To verify this view, I proceeded to try the effect of a *partial* filling of the tube with hot water, conceiving that any thermo-magnetic effect should be equally developed by a part, as by its entire capacity being filled. And so it proved; for whilst a depth of five inches of boiling water doubled the original magnetic action of the vessel, a depth of nine inches only increased it 10′, and a depth of 13 inches only 5′ more.

The experiment was next varied by filling one half of the vessel with cold water, and, by the intervention of a disc of wood above it, the upper half with boiling water. On completing the operation, the lower part having the temperature of 50°, and the upper that of 165°, the deviating action of the base (5·3 inches from the compass) was only augmented 1° 45′. The change in the magnetic condition of the top of the vessel, however, was not tried. On mixing the water within it, by moving the wooden disc up and down, the deviating action rose 30′ higher, with a mean temperature of 102°.

As it now appeared that a fair and unembarrassed view of the simple effect of temperature was obtained by heating the tubular vessel whilst in its place on the deviation-board, I thought it desirable to try the proportion of increase of

magnetic capacity, by heat, in like manner, on iron of a more massive description. For this purpose, and for enabling me to heat the iron regularly and equably, I placed a heavy piece of iron tubing, 12 inches in length and 1·5 inches in external diameter, *within* the tinned-iron vessel. Their united action on the compass, when upright, 5·5 inches distant from centre to centre, with the tube filled with water of the temperature of 50°, produced a deflection of 24° 12′. Soon after the lighting of the lamp the deflection of the needle began to increase, and continued, as tested at each 20° or 30°, with apparent regularity, up to the maximum temperature of 190°, when it was found to be 27° 14′,—indicating an augmentation of capacity for terrestrially-induced magnetism of 3° 2′ for 140° of temperature, or 1′·3 for each degree on an average. In the heating of the tinned iron-vessel by itself, the ratio of increase in magnetic capacity was, on a mean, 1·8 per cent. of the original capacity when cold, (comparing the tangents of the angles of deviation,) for 10° of temperature, upward; and in the case of the iron tube within the tinned iron-vessel 1·03 per cent. increase for each 10°.

This increase of magnetic action from elevation of temperature, it was found, was, (as in the case of the magnetism of red-hot iron cooled in a

vertical position,) mainly, but not altogether, retained. In the case of the tinned vessel alone, there was a reaction, on being cooled down to 48° of the thermometer, of about 0° 16′, or about one-fifth of the gain; and in the case of the tubular iron within the tinned vessel, a return of 0° 40′, on cooling down to 47°, being a somewhat larger proportion.

These results on the increase of capacity with heat, in malleable iron, for induced magnetism, open out a considerable field of enquiry as to the effects of differences in the quality or denomination of metal, and in the form, or massiveness, of similar metal. For, for reasons stated in the foregoing chapter, our present investigations with *elongated tubes*, on the effects of temperature, yield information on the ratio of the magnetic changes for the special cases only; but cannot apply to cases of iron bodies of different proportions, as to massiveness, nor to metals of different qualities or degrees of hardness. But, as it would require more time than I can conveniently bestow on the investigation to pursue it thoroughly, I must now allow this limited measure of research to suffice. Still, even as to this limited extent of research, we shall find it, I trust, not altogether devoid of practical use, when, in a subsequent chapter, the investigation of a subject of high consideration and national

importance will be submitted to the scientific and nautical reader.

Sect. VII.—*On the Augmentation of the attractive or lifting Magnetical Powers in Iron Plates or Bars by the agency of Mechanical Violence.*

The magnetical powers developed in iron by simple terrestrial induction, were shown, in the preceding chapter, to be sufficient for yielding both *attractive* and *directive* capabilities. Aided however, by mechanical violence, these effects, as would reasonably be expected, are capable of very considerable augmentation.

In attractive capabilities, the augmentation becomes striking and interesting, yielding, on trial of the effects on the various plates and bars referred to in former experiments [10, 11, 12], the results following:—

[23. *Exp.*]—A thin plate of annealed iron, (which had been used in experiment 11) by hammering on the sides whilst held upright, had its attractive powers about doubled; and the same plate, in the middle of a bundle of twelve plates tied together and hammered in the mass, lifted (barely) a nail of 20 grains weight, and just raised from the table another of 36 grains.

[24. *Exp.*]—Much greater effects, however, as to the measure of augmentation of attractive power, were obtained with an annealed bar of round iron, three feet in length and three quarters of an inch in diameter. On being well hammered on the top, or on the sides, whilst held in a position vertical to the horizontal, this bar lifted by its lower end, which was rounded and smoothly polished, various nails and pieces of tinned iron tubing, some of them being of much greater weight than those raised by the plates. After several repetitions of the hammering, the bar became so highly magnetic that it fairly lifted from the table a tube of tinned iron of four and a half inches length, and a hundred grains weight!

[25. *Exp.*]—A still higher degree of attractive force was ultimately elicited in the three-feet iron-bar by heating one of its ends to the temperature of about 250°, and subsequently hammering it on the sides whilst held, hot end downwards, loosely in the hand so as to vibrate freely and emit a ringing sound under the operation. By this mode of treatment, the magnetism of the bar was so considerably augmented, that it was now found to be capable of lifting a tube of tinned iron of the length of six inches, and of the weight of one hundred and sixty grains!

In this result, however, it should be observed, we have an additional agency engaged in the magnetic development beyond those of terrestrial induction and percussion, — the unequal heating, that of one end only, bringing into action the *thermo-magnetic* principle.

CHAPTER IV.

ON THE DEVELOPMENT OF MAGNETICAL PROPERTIES, BY PERCUSSION, IN STEEL AND IRON, AS AIDED BY CONTACT WITH IRON BARS PREVIOUSLY MAGNETIZED BY HAMMERING.

SECT. I.—*On the Principles, in Inductive Science, by which these Researches were guided, with a Description of the Apparatus and Processes employed.*

THE remarkable extent to which terrestrial induction, when aided by mechanical action, had been found to be available as an originating influence for the development of magnetism in iron, led to the enquiry, whether the magnetism thus elicited might not, in its turn, be applied for the attainment of still higher degrees of magnetic development? For it appeared reasonable to expect that, when such considerable degrees of energy could thus be simply and directly attained, an accumulative power might be gained by means of a succession of substances having like magnetic capabilities, in which the principal mass, receiving its influence directly from the earth, might serve to elicit additional energy in

other connected masses. For it was considered that, in the hammering of a magnetizable substance on the top of, and in contact with, a bar already made magnetical, there would be a two-fold influence operating for the development of polarity therein,—the original power of the earth, and the power of the auxiliary bar. And it was further considered, that the mechanical action which enabled the earth's inductive influence to develop so considerable a degree of energy in *iron*—a material of but feeble *retentive* capabilities,—might, in the employment of *steel* as the ultimate recipient, enable the terrestrially magnetized bar of iron to elicit, in the superior material, strong and permanent magnetism; and the more so, as was supposed, by bringing the energy belonging to mass, in a large bar of iron, to act on a comparatively small portion of steel.

These anticipations were in no respect attended with disappointment. On the contrary, the trial of the influence, under percussion, of large masses of iron in eliciting magnetical power in wires or small bars of steel, was highly satisfactory and successful. The encouragements thus yielded led to further combinations, on the same leading principles, whereby additional efficacy in the processes was attained; the improved results, also, were applied, ultimately, to the obtaining of powerful magnets, having no

other agency for the development of their mysterious properties, except terrestrial induction aided in its action by percussion.

The details of these investigations having, as to the original experiments, appeared in the Philosophical Transactions for 1822 and 1824, it will now suffice to describe the leading results originally obtained, connecting and embodying with them such additional facts as subsequent, and more recent, researches have contributed.

The magnetizable substances employed, in the researches of this chapter, consisted of bars of malleable iron and common iron pokers of about three feet in length; one large and ponderous bar of round iron; various small bars of soft steel and steel wires of different thicknesses and lengths; and two small straight bar-magnets. For the development of magnetic power by percussion, three hammers, all carefully tested as to their being free from magnetism, were employed, which were of the respective weights of 2·5, 12 and 22 ounces. For the determining of the degree of power developed, two tests were employed,—the weight of iron, that the bar or wire would lift, and its quantity of deviating action on a small compass.

For the first test, several common nails, of different sizes, were prepared, by the filing and

polishing of their points, so that a close contact might be secured. Their weights varied from 1·5 up to 482 grains.

For the second test, a delicate magnetic needle of about two inches in length was made use of; the quantity of deviation being observed which the magnetized wire or bar might produce when presented to the compass in a certain position and at a certain distance on the deviation-board.

No *exact* value, it may be remarked, could be given to the number of blows, because, having struck them by the hand, they must have been liable to considerable variation in intensity; and, also, that the lifting power could not be considered as an exact measure of the magnetism developed by the process. For broad and general comparisons, however, these defects were not calculated to vitiate the satisfactoriness of the experiments; whilst a considerable degree of precision, wherever needed, was easily secured by the application of the deviation test.

The general process of magnetical development by percussion, consisted in hammering, first of all, the iron bar, whilst held in an upright position, or, where the highest effects were required, in the line of the earth's magnetic axis; and then hammering the steel bar or wire whilst resting on the top of the iron,—the steel and iron being supported in the same vertically-tend-

ing straight line. Under these circumstances, the terrestrial indication must yield, by its direct action, northern polarity, to the lower end of both bars, which, in the case of the steel bar, must be augmented by the full energy of the southern polarity in the upper end of the iron, inductively operating on the end in contact with it.

Sect. II.—*On the comparative Gain of Magnetical Development, in Bars or Wires of soft Steel, when hammered on Iron Bars, and on non-magnetic Substances.*

A cylindrical bar of soft steel, 6·5 inches long, and weighing 592 grains, was employed for this preliminary enquiry. After being repeatedly hammered whilst resting with one end on a lump of pewter, or on a surface of stone, it was found to be so far magnetic as to lift a nail of 6·5 grains weight, but by no quantity of percussion, when thus supported, could it be made to lift the next nail in the series of 11 grains.

But when the same bar of steel was hammered, vertically supported, on the top of a parlour poker—though the poker *was not previously hammered*—it lifted with its lower end, after 22 blows with the small hammer, a nail of 88 grains; and, on using a larger hammer, it

received a considerable increase of power. But a maximum, under these powers of development, was now found to be reached, so that further percussion yielded no advantage.

On the steel being inverted, so that the north pole was upward, and at variance with the magnetizing tendency of both the iron bar and the earth, the previously acquired magnetism was nearly destroyed by a single blow; whilst two blows sufficed to change the poles.

Hammering the end of the bar whilst held in the plane of the magnetic equator, also, consistently with theory, destroyed the polarity; but the full effect was not produced until very many blows had been struck.

When the poker had been *previously hammered*, an increase of magnetic effect on the steel was obtained; a single blow, with both bars in an upright continuous line, being now sufficient to enable it to lift about 20 grains; and when the end (which had been squeezed out by the former operations) was hammered into a kind of cup, so as to be easily bruised, the steel bar, acted on by a single blow, was rendered capable of lifting betwixt 30 and 40 grains. After ten blows, the highest effect yet elicited was produced, in the acquisition of a lifting power sufficient to support a nail of 188 grains, being nearly one-third of its own weight!

The quantity of the magnetical development in different steel bars, was found, within the limits tried, to bear a certain, but not accurately determined, proportion to their lengths. Thus a quarter-inch cylindrical bar of steel, 5 inches long, after receiving 20 smart blows, produced a deflection of the needle, at the distance of three inches, of 13°, and lifted 6·5 grains. Another piece of the same rod of steel, 7·25 inches long, after similar treatment, produced a deviation of 24°, and lifted 45 grains. And a third bar of the same kind, 12 inches long, after 20 similar blows, occasioned a deviation of the needle of 33°, and easily lifted 88 grains.

The shortest piece of steel, it was observed, received the full effect in magnetic development by the first two blows; but the longer pieces continued to increase in energy as the percussion went on. These bars did not receive a power equal to that first employed: the difference was probably due to their greater hardness, or, possibly, to the inferior quality of the steel employed in the latter experiments.

The comparative gain of magnetical development, when the steel was hammered on the top of an iron bar, over the power when hammered on hard unmagnetizable substances, was thus proved to be decided and extensive. The gain, as derived obviously from the inductive action of

the poker within the extreme limits of these experiments, being in the proportion, in lifting power, of 188 to 6·5, or nearly 30 to 1.

The elementary power thus developed in bars of soft steel, which was found to be so considerable, was made available, even in the earliest of these researches, for the eliciting, by well-known multiplying processes, very high degrees of magnetic energy. Thus, six bars of soft steel, each of them eight inches in length by half an inch in breadth, being magnetized by the percussion process, proved very effective in their application for mutual augmentation. For this object, two of these bars, connected at the extremities by two short pieces of soft iron in the form of a parallelogram, were rubbed with the other four bars in the manner of Canton, by which their original power was greatly increased. These, being substituted for two of the bars of the operating set, were applied, with increasing efficacy, to the new parallelogram; and the latter, after being thus strengthened, became effectively available for the improvement of the third pair of the series. After treating each pair of bars in regular succession, and through several repetitions of the process, the whole of the bars were found to be in a very high degree magnetical, apparently to the extent of their capacity,—each pair readily lifting a weight of above eight ounces!

In pursuance of enquiries on the effects of this new process of magnetization, it became early apparent, that a perseverance in the process in the original direction of the poles, without change, yielded a tendency favourable to the magnetical development. For any bars which had been strongly magnetized, and had had their magnetisms destroyed or neutralized (either by hammering, heating, or simple contact of a magnet), were always found to have a much greater facility for receiving polarity in the same direction as before, than the contrary. Hence it generally happened, that one blow with the original north end downward, produced as much effect as two or three blows did with the original south end downward.

Sect. III.—*On the Development of Magnetism in Malleable Iron and Cast Iron, by hammering on Iron Bars.*

The effects of percussion on magnetical development, as applied simply and directly to bars of iron in an upright position, has, in much variety of circumstances in the investigations, been already shown; but the cases heretofore recorded have not touched upon the modifying or

augmenting influence to be derived from the interposition of an auxiliary bar of iron.

On this point, indeed, no very considerable experiments have yet been tried; and none beyond those already on record in the Royal Society's Transactions. But the results therein set forth may, for the greater completeness of our present descriptions, be briefly recapitulated.

A small bar of *soft iron*, similar in size and form to the steel bar first employed, weighing about 600 grains, was treated in a like manner, having been hammered for a considerable time whilst held vertically upon the poker. It became attractive in an unusual degree for such a material, obtaining *retentive* magnetism sufficient to deflect the needle in an angle of 13°, and to lift a nail 6·5 grains in weight.

A small bar of *cast iron*, of the same size and form as the last, was subjected to similar action, and under the same arrangements, for the further trial of the capabilities of the process on this quality of metal. The percussion resulted in yielding a magnetic power capable of lifting a nail of 37 grains weight. After it had acquired this extent of attractive energy, its magnetism was nearly destroyed by five blows in the reverse position; that is, with its *south* pole, in contact with the top of the poker, held downward.

SECT. IV.—*On the Effect, on permanent Steel Magnets, of hammering on an upright Bar of Iron.*

IT was only sought, in my experiments in this department of research, to ascertain something of the *general influence* of the process under consideration, as applied to the case of permanent bar-magnets.

For this object, a straight-bar magnet was selected, of tempered steel, seven inches long, ·5 inch broad, and ·14 inch thick. It was first hammered whilst held vertically on a rod of iron, with the north pole downward,—a position the most *favourable*, under terrestrial induction, for the retention, if not the augmentation, of the original power. But the effect of percussion, in this case, was to deteriorate the magnetic energy, and that so considerably, that the first 5 blows reduced the power from 45° to 37° deviating action on the needle, whilst 80 blows, altogether, reduced it to 25°. A further hammering, to the extent of 20 blows, produced no change.

The magnet was next inverted, and, in the *unfavourable* position of south pole downward, the hammering was renewed. A single blow now reduced the residual power of the preceding experiment from 25° to 20°, and 30 more blows

to 14°, when the deteriorating effect seemed to be about suspended.

With a view of ascertaining how far this reduction was due to percussion, and how far to the influence of the iron rod, respectively, the same steel bar, being remagnetized up to a deviating action on the needle of 50°, was hammered, whilst held upright on a lump of pewter, *south* end down, when the first 10 blows were found to have reduced the deflective action to 37°, and 10 more blows to 33°. Turning the north end downward (the most favourable position) and continuing the hammering, a further reduction, from 33° to 24°, was effected by 60 blows. After this a series of 80 more blows, partly with the south end and partly with the north end downward, diminished the power only to 23°, being but 1°.

Hence it appeared, that a somewhat greater reduction was effected by the percussion, whilst the magnet rested on a hard unmagnetic substance north end downward, than when on the iron rod; and, consistently with theory, the greatest reduction of all was produced when the magnet was hammered upon the iron rod with its south pole downward.

The effect of percussion on a small *magnet of soft steel* was found to be singularly powerful. Though the bar was originally capable of sus-

taining a key of upwards of 1000 grains in weight, the whole power was destroyed by five blows when hammered, whilst held upright on the top of the poker, with its south pole downward.

Sect. V.—*General illustrative Experiments on the Development of permanent Magnetism in Steel Wire by Percussion.*

As much surprise and interest are wont to be elicited, by the development of attractive properties in a piece of steel wire by a process so apparently inadequate, and by an agency, with the general observer, so little appreciable,—it may not be deemed superfluous, perhaps, to give a reiterated description of our process in a more popular and general form, and adapted to means and materials to be found in almost every house. For, for this experiment, no other materials or apparatus are necessary, but a steel knitting-needle, a hammer, and a common kitchen (or iron) poker.

[26. *Exp.*]—Take a steel knitting-needle, of the *thicker* kind in common use, (a very small wire being liable to bend) and break off a portion of about three inches in length. This must be

done without the bending of the wire, which would interfere with the effectiveness of the percussion. In the absence of either file or plyers, a common door, or other, key will be found particularly effective for this operation,—a key being selected having a ward-slit of such width as to receive the wire with little or no space to spare. Thus supported in the slit of the key, the wire, at the required length, can generally, by a sudden pressure, be broken *short* off.

The poker being held in an upright position in the hand, or supported betwixt the knees whilst resting with its point on the floor, must then be well hammered, by blows on the top or otherwise. If it be of hard substance, or small mass, the hammering will require to be considerable; if soft and of large mass, a dozen or two smart blows will be sufficient.

Whilst the poker is still supported in an upright position betwixt the knees, so as to leave the hands at liberty, place the steel wire upright, with the smooth and rounded end downward, on the middle of the knob of the poker, and strike it fairly on the upper end. A single blow, if smartly and firmly struck, will probably develop an attractive energy sufficient to lift, by the downward point, a small sewing needle; and a few moderate blows, fairly struck, will yield a degree of attractive force capable of lifting small nails

by their polished points, or the larger kind of sewing needles by their thicker extremities.

Should the wire be bent under the percussion, the experiment will not be so successful, though by straightening it, and then hammering it again more carefully, a characteristic and satisfactory polarity may be elicited.

A brush of iron filings will in any case be sustained, as well as fine sewing needles; but very little practice in the manipulations will enable the operator to produce the most striking of the usual phenomena.

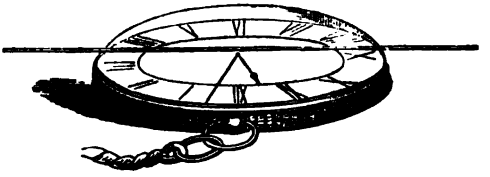
Steel knitting-wire has been suggested for this experiment, as possessing very good capabilities for the magnetic development, and at the same time being generally at hand. It may be well to notice, however, that should the wire accidentally selected for experiment be found very hard and brittle, it will scarcely answer the purpose unless reduced in temper by heating in the fire until it assumes a dark blue colour.

The very best material, it may be added, which, for the object before us, I have happened to meet with, is the steel wire manufactured for watch-making purposes, wherein a superior quality of metal is usually employed. A wire of this kind of the size of a crow-quill, and about four inches in length, will be found admirably effective, es-

pecially if the hardness be somewhat reduced by a moderate application of heat. The end to be employed for attraction—which must be the lower end when it is placed on the poker—should be rounded and nicely polished.

[27. *Exp.*]—Another appropriation of magnetical influence thus developed by percussion, which we shall also describe familiarly, is for the ready production of *a compass*. For this object the requirements are the same as in the last experiment, with the addition only of a watch, or watch-glass.

FIG. 11.



Break off a portion of steel wire, as before, of about three inches in length, and magnetize it by the process just described. Then, having a watch on the table, face upward, place the magnetized wire, as represented in the annexed figure, upon the centre of the glass, balancing it carefully in a horizontal position. Thus supported—where the straight wire can only rest, because of the curvature, upon a portion of glass being virtually a *point*—it will turn into the

magnetic meridian, and traverse with all the characteristic properties of a compass-needle,—the downward end, whilst under percussion, being always the north pole.* The watch-glass, it should be observed, must be quite clean and free from scratches in the centre; and the wire, also, in the place whereon it rests, must be clean and well polished, or the free compass-like action will be prevented by an undue measure of friction. In any case, however, the freedom of motion will be increased by any slight vibration, such, for instance, as may be produced by tapping the table, near the place of experiment, with the knuckles or points of the fingers.

The wire thus carefully poized may, with a little management, be made to obey the attractive and repulsive influence of the magnetic poker, according as the lower end is presented to its southern or northern pole. The repellancy is the most curious; for holding the poker in an

* An incident of much personal interest connected with one of my early exhibitions of the percussion experiments may not unfittingly, I hope, be here noticed. I happened to be present at a breakfast at Whitby, in the year 1847, given to the two celebrated engineers, the Stephensons, father and son. In a speech by the honourable Member for the Borough, Mr. Robert Stephenson, he was pleased, in generous and characteristic frankness, to say—that 'the circumstance which first turned his special attention to mechanical science was the witnessing of my magnetical experiments, at a breakfast at Professor Jameson's, when a student in Edinburgh.'

upright position with the point, or north pole, near the north end of the wire, the latter will retire whilst the poker is advanced, so as easily to be made to revolve as if suspended on a regular pivot!

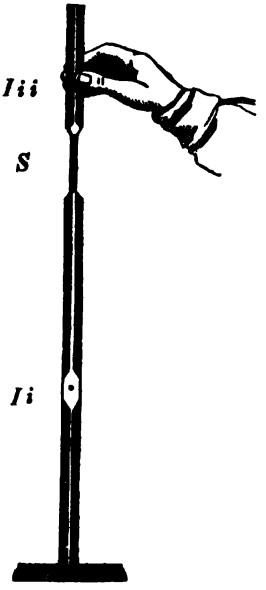
SECT. VI.—*Description of the* COMPOUND PROCESS *for the Development of Magnetism by Percussion.*

IN the experiments hitherto described, a single rod of iron was used, and the bars or wires of steel were hammered upon it, whilst both were supported in a vertical position. In this case, the magnetism of the iron bar, after hammering, was employed inductively, for the development, under percussion, of the latent magnetisms of the steel wires or bars. But here the magnetism of the iron had effect, directly, only upon the lower end of the steel; the polarity of the upper end being merely consequential. Hence it appeared probable, that, were the steel bars or wires placed betwixt *two rods* of iron, and thus subjected, either directly or indirectly, and through the medium of either rod, to percussion, they would derive a *double influence* from the magnetisms of both rods of iron acting consistently and simultaneously upon their northern and southern poles. The effect, it was conceived, ought to be

such as greatly to augment the magnetic energy elicited by the ordinary percussion process.

As, however, two long rods of iron could not be so easily managed by an individual operator, as a short one above with a long one below,—this arrangement, though not calculated to be so highly effective, was adopted.

FIG. 12.



This apparatus — with the occasional substitution of a very large bar of iron for the one ordinarily employed — is represented in the figure in the margin. *Ii* is a bar of iron, three feet in length and an inch in diameter, terminated conically above, and fixed, for greater convenience in the manipulations, in a wooden base. *Iii* represents the shorter bar of iron, a foot in length, and an inch in diameter, having a conical termination below; and *S* the steel bar or wire designed as the recipient of the magnetic energy to be developed. The three portions of the series, it will be observed, are arranged in a continuous straight line, in a *vertical* position,—an approximation to paral-

lelism with the earth's magnetic axis, sufficiently near for the purposes in view, and only in a very small degree inferior in effectiveness, in our high magnetic latitude, to the most perfect adjustment of position.

For convenience in supporting the intermediate steel wire, the conical ends of the two bars were blunted, and a shallow hole drilled in the centre of each truncation; whilst the extremities of the wire to be interposed were rounded so as to fit into the depressions in the proximate ends of the iron bars. And that the upper end of the lower bar might not be bruised or deformed under the preliminary percussion,—a third bar was provided, as the medium for the action of the hammer, having its lower extremity hollowed like a cup, to fit upon the conical termination of the larger bar.

In using this apparatus, the lower bar was first hammered through the medium of the occasional piece of iron just described; and then the hammer was applied to the top of the pile as arranged in the series represented in the figure, whilst the effects of the magnetic development were, from time to time, tested by the lifting power of the steel wire.

For obtaining the best results in this mode of trial of the magnetism of the steel wires, I procured a new series of nails of different weights, made

specially for the purpose of a fine quality of soft iron, with broad flat heads, so as to stand steadily with their points upwards; for in this position, the points being blunted and polished, they are the most readily lifted. The whole of the nails, on the completion of the series, indeed, were finished in a neat and workmanlike manner, so as to constitute an important, and frequently available, portion of a general magnetical apparatus.

The original series consisted of fourteen nails, rising, in somewhat irregular progression, from 1·5 to 482 grains, besides a few occasional *weights* for being attached to any nail which might be freely lifted, and where the interval of size betwixt it and the next larger of the series might be considerable.

Sect. VII.—*On the comparative Effects of the* Compound *and* Simple *Processes, in the Development of Magnetism in Steel Wires by Percussion.*

The steel employed in this enquiry was all of the best description of watchmaker's wire. It was chiefly of the diameter of one-eighth or one-sixth of an inch; but was employed in various lengths, from that of 2·5 inches to a foot. It was tried in its original, and somewhat hard,

state, as when drawn, and also after having been softened by heating. But it is chiefly to the gain in power, by the addition of the upper auxiliary bar, to which we have, in this section, to refer. And the general fact of the superiority of the compound process, (with the exception only of one or two special cases,) was abundantly established.

Thus, in a steel wire of five inches in length and weighing 167 grains, the maximum effect of the simple process was the development of an attractive force capable of lifting betwixt 186 and 246 grains; whilst the compound process readily augmented the lifting power of the same wire so as to enable it to sustain a nail of 326 grains. And on a repetition of the trial, the wire, on the simple process, obtained a lifting power of 246 grains, which the compound process increased to 345. But the comparative advantage was the greatest when a short piece of wire—2·5 inches only in length—was used. In this case, whilst the simple process only developed an attractive power capable of lifting betwixt 56 and 88 grains, though the wire was repeatedly subjected to a course of hammering; the compound process augmented the lifting power, by 12 blows only, up to 186 grains, indicating three times the former magnetic energy.

On the other hand, the application of the

compound process to a *long* wire—12 inches in length by one-sixth of an inch in thickness—was productive of very little advantage. Nor was the compound process of so evident an advantage when a large and massive bar of iron was used below: in this case, however, the failure of effect was probably occasioned by the very small size of the upper rod, in comparison of the magnitude and mass of the lower.

Sect. VIII.—*On the Effects of* Temper, *in connection with the Degree of Magnetic Energy developed by Percussion.*

The result of enquiries in respect to the effects of *temper*—so long as the agency of the moderate-sized bars of iron, represented in the figure, were employed—was conformable to the general law of magnetics; namely, that the *softer* the temper, the more susceptible does the steel become for the magnetic condition. This fact was elicited, in reference to the development of magnetism by percussion, in a considerable extent and variety of experiments.

A wire of five inches in length, for instance, in the state in which it was drawn, could only be made to lift 73 grains, even under the compound process; but the same wire, on being

softened by heating to redness, readily lifted, after nine blows on the simple process, 186 grains, and after 80 blows, under both processes, its lifting power was augmented to 326 grains, being nearly twice its own weight, and almost five times the power it had acquired in its unreduced hardness.

But this superiority of susceptibility of softened steel for the magnetic energy, was rendered still more conspicuous on the employment of a long piece of wire. This wire, 12 inches in length, being struck 20 to 30 smart blows, on the simple process, when in its original temper, failed, as to attractive power, in lifting a nail of only 18 grains weight; whilst the same wire, on being *softened* and still operated on by the simple process, lifted 186 grains after only 16 blows, a power, which, after 14 blows more, was increased to 326 grains!

In another set of experiments, the result was analogous. A wire of five inches in length, which, when unreduced, had, by five blows on the simple process, lifted 37 grains, and by the same number of blows on the compound process, 73; was enabled, after being softened, to sustain, under the like treatment, 186 and 265 grains.

An exception to this general effect requires to be noticed. It occurred in a case where a very massive bar of iron had been employed, and when

that, by very much and heavy hammering, had gained a highly magnetic condition. In this instance, an *untempered* wire of only 4·5 inches in length, and in weight but 150 grains, was made to lift 482 grains by the simple process, and, on one particular occasion out of many trials, 602 grains, or four times its own weight, by the compound process! Hence was derived, in the use of this powerful apparatus, as high an effect, magnetically, on the new unreduced wire, as had almost ever been obtained, by the original apparatus, on the softened steel. But the effect, though apparently anomalous, was not really inaccordant with the laws of magnetism deduced from our former investigations.

The facility with which magnetism may be developed in softened steel wires, by this process, is very striking. The first five blows on a softened wire of five inches in length, in one instance, produced, under the simple process, a lifting power of 73 grains, nearly half the weight of the wire. In another case, with a long wire whose magnetism had been totally destroyed by heating to redness, two blows only, on the simple process, produced a lifting power of 186 grains.

SECT. IX.—*On the Effects of* MASS *in the Bars of Iron, on the Quantity of Magnetism developed by Percussion.*

IT was most reasonable to expect that, if such marked and characteristic advantages, in the development of magnetism in steel by percussion, were gained by the agency of common pokers, or of an iron-bar apparatus of similar general dimensions,—such advantages might be proportionally augmented by the employment of ponderous and massive bars of iron.

On the putting of this deduction from theory to the test of experiment, with a bar of round iron of eight feet in length, and 1·75 inches in diameter, it received, as to the general law at least, satisfactory verification. Thus a long wire, which, in the use of the smaller apparatus, could only be made to lift betwixt 326 and 389 grains, —received, on application to the ponderous and previously well-hammered bar, an increase so considerable as to enable it to sustain a weight of 662 grains. And when by the small apparatus, under the simple process, the highest power that could be given to a softened wire of five inches length, was that of sustaining a nail of 246 grains; the use of the larger bar was found so to augment the power as to enable it, by the

same process, to lift 533 grains,—being more than double its former development.

But the most striking differences, as already intimated, were realized, in this particular case, on the employment of *harder* wires. Thus on a wire in its original degree of hardness, whose lifting power, with the smaller apparatus, could with difficulty be raised to about 70 grains,—the large bar acted so effectively as to enable it readily to lift 246 grains; and by continuing the process, on several successive occasions, it lifted, ultimately, 602 grains, being nearly nine times the maximum power attainable without the aid of the massive bar.

Hence it would appear that, in the use of any one apparatus, in iron bars, there is a limit to the power which it is capable of developing; whereas, from the great augmentation of effect obtained by the use of the larger apparatus, it becomes probable, that were iron bars, sufficiently large and massive employed, there would be no limit to the attractive force developed in the steel wires until they were magnetized to the full extent of their capacity.

An approximation to a like result, it also appeared probable, might be obtained by means of a long continued and powerful application of percussion with an ordinary apparatus. Under this expectation, which to a certain extent only

was realized, I persevered in the operation day by day, with the same apparatus and on the same wire; but, after the iron bars had acquired their maximum energy, the power of the wires soon ceased to increase, and then, it was found, that no future repetition of the process, however laboriously conducted, gave any additional power.

It thus became evident, that the suspension of augmentation did not arise from the want of capacity in the *steel wires* for magnetism, the wires not being near a state of saturation; but that it arose from the incapability of the *iron bars* attaining, through the medium of terrestrial induction, any higher magnetic energy. The maximum in their condition, it would appear, determines the maximum in the condition of the steel. For the quantity of effect produced by any particular iron bar, or set of bars, seems to follow the ratio, as by theory we might expect, of their own magnetic development.

CHAPTER V.

INDICATIONS, EXPLANATORY OF CERTAIN PECULIAR MAGNETICAL PHENOMENA, DERIVED FROM THE FOREGOING RESULTS.

THE researches and facts which constitute the subject matter of the foregoing pages, connect with, and serve to elucidate, some otherwise very mysterious, and, as generally considered, anomalous magnetical phenomena. From among the variety of phenomena, to which our results may apply, we shall attempt the elucidation, chiefly, of these three: — 1. The elucidation of the effects of *mechanical violence* in aiding magnetical development: — 2. The elucidation of the increased development of magnetical properties by *heat*: — 3. The probable explanation of the anomalous magnetical action in iron bars cooling down from a *white* to a *red* heat.

SECT. I. — *Elucidation, theoretically, of the Effects of* PERCUSSION, *or other* MECHANICAL VIOLENCE, *in aiding Magnetical Development by Terrestrial Induction.*

IN the natural condition of ferruginous or other ordinarily magnetizable substances, the inherent,

or molecular magnetisms, are in a condition of mutual and general neutralization. The juxtaposition of a magnet, or the inductive influence of terrestrial magnetism, *tends*, in all cases, to develop a measure of polarity, having relation, as to energy, on the one part, to the susceptibility of the substance, and, on the other part, to the weight and form of the mass. Malleable iron is, of all ferruginous bodies, the most susceptible of terrestrial induction, yet, even in the purest and most ductile qualities, there is a resistance in the metal of the magnetical development. In hard and hammered iron this resistance is very considerable; in the annealed and ductile qualities, less so.

The inductive *tendency* of any magnetical force, is to develop a specific degree of magnetic energy, regulated by the capacity of the recipient, and the magnetic energy of the inducing cause. But the *molecular rigidness* restrains the operation of the inductive force, so that a comparatively small measure of energy is, quiescently, elicited. The influence of percussion, or other mechanical violence, herein appears to become operative and influential—in relaxing, as it were, the molecular rigidity and yielding effectiveness to the inductive tendency, and thus aiding the more complete magnetic development. And it would appear, from the unimportance of the place

in any iron plate or bar on which the act of violence may be impressed, that there is *an universal sympathy in all the magnetical elements of the same mass;* so that, any disturbance of the existing polarity in any particular spot on, or within, it, is instantaneously distributed throughout the entire substance.

And this effect, it may be observed, is no more than what we perceive in a variety of well-known cases of the distribution of limited or partial action; as, for instance, that of the conduction of vibrations through a beam of solid timber, wherein a scratch of the finger nail, or the tick of a watch, at one extremity, is so thoroughly distributed as to be clearly perceptible by the ear at the other end of the beam, however massive or long.

The theory of the development of high magnetical powers in steel wires, when hammered upon iron bars previously strengthened by the same process, has already engaged some degree of consideration. But this theory, in the present connection, we may, not uninstructively, I hope, now recast, in order to render more intelligible the extension of our general notions of the phenomena.

The magnetism, as augmented in a bar of iron by hammering it in an upright position, becomes

in some measure available, by simple induction, for the transient development of magnetism in a steel wire placed upright upon its upper end; but this inferior development is greatly advanced, as well as rendered permanent, by the renewal of the process of percussion upon the wire, whilst the wire and the bar are held in contact. By continuing this treatment, the polarity of the steel is progressively augmented until it has acquired a maximum, depending, not so much on its own capacity for magnetism, as on the capability of the iron to develop it. But this condition, it has been shown, is only a maximum so long as the same iron bar or bars are used, and so long as their magnetic energy undergoes no change; for if by any means their polarity be increased, the attractive force of the steel wires will rise in proportion.

From the whole of the phenomena viewed in connection, the simple general fact would seem to be reduced to this,—that percussion applied to magnetic or magnetizable substances, in contact with one another, disposes them to an *equality of magnetic condition.*

If this view of the subject be correct, we have a satisfactory explanation of some phenomena which were otherwise very obscure. We see why *large* bars, or wires of steel, whilst acquiring, by virtue of percussion upon iron bars, a much

higher *directive* action on the compass than *small* ones, exhibit little or no superiority in their lifting powers. And, above all, we have a fair explanation of the apparently contradictory propositions—that percussion diminishes, and has a tendency to destroy the energy of magnets; and that percussion has a tendency to develop polarity in iron and steel not previously magnetic. For both these propositions are undoubtedly true; but under different conditions. Percussion, whilst it diminishes the energy of a highly charged magnet when held alone, or even upon an iron bar, would probably tend to augment its energy if it were placed, during the operation, with the consistent pole in contact with that of a *more powerful* permanent magnet,—such being the analagous condition of a wire magnetized upon a bar of iron by percussion. These different effects would appear, I think, to be the necessary result of a tendency to equality of condition,—a tendency which is precisely similar in respect to bodies of unequal temperatures when placed in contact, or even in juxtaposition.

SECT. II.—*Elucidation, theoretically, of the increased Development of Magnetic Properties by Heat.*

IT was found, in my orginal experiments, that the spontaneous action of terrestrial induction on an iron bar *heated to redness*, was more than *double* this action on the same bar when cold; and, in one experiment (requiring, however, much reduction for the special nearness of the compass-needle when greatly deflected) very much greater. The proportion of gain in power, indeed, by the heating, seemed to come very near that obtained by mechanical violence.

The high spontaneous magnetic development in the heated bar, is to be ascribed, obviously, to the operation of the same cause as that by which annealed iron, in its diminution of rigidity, receives, spontaneously, more magnetism than iron of a harder texture. For as, under this very limited change in hardness of texture, such considerable difference, as we have shown, is produced in the magnetic capacity of the annealed iron, over that of crude plate or bar iron, it seems reasonable to infer that, under the further relaxation of the texture by heat, a still greater susceptibility for the spontaneous operation of terrestrial induction should be yielded.

This explanation, it may be observed, receives

additional support from the facts elicited in our experiments on the progressive augmentation of magnetical development by moderate increments of temperature. For the high magnetic susceptibility of malleable iron when heated to incandescence, and thus nearly approaching the condition of semi-fluidity, might possibly have been regarded as a particular and insulated fact; but the ratio of increase with moderate augmentations of temperature points, obviously, to a general law, and, as to me it appears, plainly resolves the explanation of the increase of magnetic capacity into the *softening* of the metal,—the softening influence being accounted for on the popular principle of the extension of space among the molecules of the metal.

Though our investigations on the effects of temperature on the magnetical capacity of iron, were so very limited in reference to varieties of form, mass, and quality of metal; yet they clearly indicated these general results:—That the magnetical power, terrestrially developed in bars of iron, is always increased by heat; that a large proportion of the increase of power by heating becomes of the *retentive* denomination, remaining after the cooling of the metal; but that a small and inferior proportion of the augmented power *subsides* as the cooling advances. These laws, however, it should be observed, have

only been elicited in a limited case; and it by no means follows that they apply to very *massive* forms.

The effect of repetitions in the heating and cooling of the iron, without neutralizing the retentive magnetism acquired under each operation, was, unfortunately, not determined. According to ordinary analogies, however, we may pretty safely infer, that such repetitions would serve progressively to augment the magnetical development, though, doubtless, in gradually diminishing quantities, until the attainment of the maximum capacity determined by the balancing of the antagonistic influences operatively without, and molecularly within, the body of iron.

SECT. III.—*Explanation, suggestively, of the apparently* ANOMALOUS MAGNETIC ACTION *on Iron Bars cooling down from a white to a red heat.*

IRON, in a state of fluidity, is found to have no capability for the magnetical development. For this development, molecular *fixedness* is necessary. Hence iron at a *white* or *welding heat*—a condition of *semi-fluidity*—does not admit of the arrangement in its molecules (?) which appears to be essential to the exhibition of magnetical properties. For this fact, as to the non-magnetic

quality of iron at a white heat, as well as for that of the (apparently) anomalous action, on the compass, of iron bars so heated during the process of cooling, we are indebted to the interesting researches of Professor Barlow.

In referring to the "anomalous attraction of heated iron, which takes place while the metal retains the high red, and simple red heat," I would venture to offer what I trust will be considered as a sufficient explanation. And in order to this, I shall first select out of the "Essay on Magnetic Attractions," the leading facts developed in this particular investigation. It will suffice to consider the results obtained with iron bars (of any of the qualities tried) of about 25 inches in length, and about 1·3 inches in thickness;—the bars being placed in the direction of the magnetic dip, when tested, and the compass held about six inches off the bars, westward from them. The results, taking the most general and consistent of the series, may be thus epitomised.

Case 1. That in the cooling of the bar under experiment, from the white heat, where there is no magnetic action, to a bright red, the needle first oscillates and then indicates a polarity in the iron, diverse from that of such bar in the cold state.

2. That the reverse or anomalous attraction takes place during the *transition state* from a

white heat to that of a general red heat only,—and changes into the proper or ordinary polarity when the whole bar is reduced to redness.

3. That according to the experiments with these particular bars, the white heat commonly remains prevalent about three minutes, when the *negative action* commences; this lasts about two minutes more, and then the *usual* attraction begins to indicate its presence. The proper action arrives at its maximum sometimes very rapidly, at others gradually; and, commonly, in a quarter of an hour from the beginning, the needle is found perfectly stationary.

4. That the *least anomalous* action, on the first cooling of the bar, is exhibited by the extremities, where, under other circumstances, the attraction is greatest: that this singular action increases with the distance of the level of the compass from that of the ends of the bar, being at a maximum (where under ordinary influences the polarity vanishes) at, or near, the middle of the bar.

5. That the *negative* or anomalous attraction, which, consistently with itself, is different in quality in the two halves of the bar, accomplishes this change by passing through a maximum in both qualities, (a circumstance so contrary to ordinary analogies as to "appear wholly inexplicable,") so that the least change of position, when the compass is opposite the centre of the

bar, 'will change altogether, both quantity and quality of this negative action.'

6. That the exact level of the bar's centre is not necessarily the point of change in the *quality* or denomination of the polarities; the *south* end of the needle, in one experiment, being attracted by the bar, and the north end in another.

7. That with the bar laid to cool in the plane of the magnetic equator but very little, only an insignificant amount of negative attraction is indicated.

8. Finally; that the bar left standing in the position in which its high magnetic energy is derived, retains that energy, with a measure of *retentiveness* sufficient to support, in some degree, the acquired polarity, when the bar is inverted; but that when the bar is thrown down whilst yet red hot, and so cooled in or near the plane of the magnetic equator, the previously acquired polarity disappears.

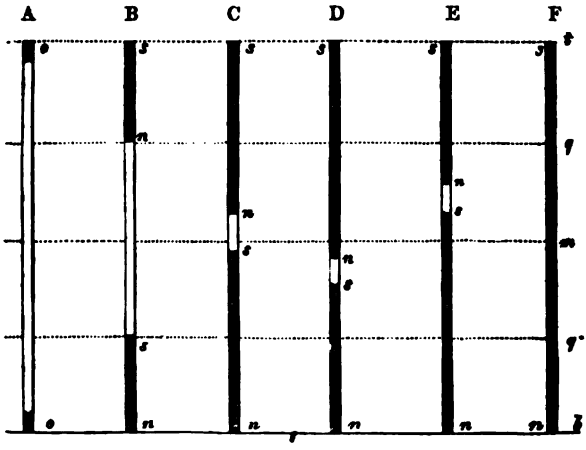
As no account is given by Mr. Barlow of the manner in which the bars under experiment were *supported*, we must assume (and I should suppose with little risk of mistake) that the *lower ends* rested on the ground, or on some solid mass of metal or stone upon the ground, and that the upper ends inclined against some other solid material. At all events, the bars could not be

kept in position without, at least, two places of contact and support, which, most probably, would be at or near the two extremities. And we may further assume that these supports would be cool, as to their temperature, or, in any case, cooler than the iron; and, if so, they must serve to chill the extremities of the bars, and so preventing an uniform and equable abstraction of the heat by the air, to urge a *progressive* cooling from the places of contact with the supports towards the centre. And if this, as seems obviously to have been the general condition of things, were the fact, then we may perceive that any bar, whilst in progress of cooling from the white heat, or non-magnetic state, to the red heat, or highest magnetic condition, would consist of two distinct and *insulated* segments—insulated as to each other's magnetic influence by the intermediate portion of non-magnetic metal—and that each segment should, under the ordinarily acting influences of terrestrial induction, have its legitimate and separate polarities. In such case, all the leading phenomena, if I have not greatly mistaken the descriptions, admit, I think, of satisfactory explanation.

The annexed figures may be advantageously referred to for the elucidation of our explanatory views. They are designed to represent Mr. Barlow's iron bars in various stages of cooling,

from the condition of an entire white, to an entire red, heat. The *shaded* portions here indicate, the supposed places and extent of the molecular consolidation, as characterised by the condition of a *red* heat; the white, the portions retaining semi-fluidity, as characterised by the condition of a *white* heat. The italic letters *t*, *q*, *m*, *q'*, *b*, with the dotted lines extending from them to the left hand, show the levels of compass observations, at the *top*, *quarter*, *middle*, *lower quarter* and *bottom*. The letters, *s n*, mark the assumed limits of southern and northern polarity, and *o* the places in the non-magnetic condition.

FIG. 13.



Under guidance, now, of these several figures A to F, we may realize visible representations of several stages in the progress of the cooling, under

the circumstances assumed, from A, having all but an entire white heat, to F, with an entire red heat. A compass placed near the level of either extremity, (agreeable to the foregoing case 4,) should, in reference to the general laws of induction, exhibit no action at A *t*, where there would be a commencing redness, nor any material action at B *t* during the early progress towards *q*, nor, in any instance, a negative action. But in the progress of the cooling from B *t* to B *q* consistently with the same case, a compass at the intermediate level, *n*, should exhibit northern polarity (apparently *anomalous* for the upper half of the bar), and southern polarity at *s*, in the lower section. The quantity of negative, or apparently incongruous, deviation, as indicated by the bar C, should increase, accordantly with the fact in case 4, by the extension of the redness to near the centre, just in the ratio of increase derivable, under ordinary induction, from augmentations in the *length* of bars being of uniform thickness. In the bar C, too, it is observable that, whilst the negative polarity should, consistently with fact, rise to a maximum near the centre, being northerly at C *n*, and southerly at C *s*,—a very slight change in the position of the compass, when *near* the level *m*, must, as noted in case 5, change altogether both the *quantity* and *quality* of the negative action;

the *quantity*, by reason of the opposing influences of the opposite polarities *n* and *s*, whilst either one or the other might be partially dominant, and the *quality*, by reason of the passing through the very small interval, at the middle of the bar, from *n* to *s*, or from *s* to *n*.

As the gradual cooling of the two halves of the bar could hardly, except incidentally, go on in exact corresponding measures, the inequalities represented at D and E, might reasonably be anticipated, wherein, as Mr. Barlow found (case 6) a compass at the centre, as at D, should indicate strong *northern* polarity, in that part of the bar, but, at E, the reverse, or southern polarity.

In the case No. 7, of a bar being cooled whilst lying in the plane of the magnetic equator, the *trifling extent* of the attraction is what would of course be looked for. Why it should exhibit *any* anomalous action on the compass at all? we do not attempt to explain, as other circumstances, not easy of detection, different perhaps from these productive of the general phenomena in upright bars, might occasion the slight measure of negative influence actually observed.

In the case No. 8, we have a close correspondence with what takes place in an upright iron bar under mechanical violence,—the extra magnetism so developed remaining unabated, so long as the

same *position* is retained, and being retained, so far as to indicate a polarity unaltered in denomination, even when the bar is inverted, and so subjected to the reverse action of terrestrial influences. Thus the cooling of the bar, under a high molecular magnetic development, yields a corresponding *retentiveness* with that produced by the hammering of the bar. The same fact, too, is precisely accordant with our results on the increase of magnetism acquired by iron tubes and bars moderately heated, in which the main proportion of the augmentation is retained, as we have seen, on the cooling of the iron.

Having thus shown, and I trust fairly and satisfactorily, the entire consistency, under our hypothesis, of the *apparently* anomalous phenomena under consideration, with the general laws of magnetic induction; it is but due to Mr. Barlow, in conclusion, to mention that an explanation, similar in principle is glanced at, at the end of the description of his personal investigations, but seems to be rejected, or considered as untenable, because not meeting entirely the phenomena recorded.

CHAPTER VI.

ON THE APPLICATION OF PRINCIPLES AFFECTING THE MAGNETICAL CONDITION OF IRON, TO ITS REAL AND THOROUGH NEUTRALIZATION.

SECT. I.—*On the general Principles which seem to affect and determine the apparent or resulting Magnetical Condition of Iron.*

WE here discriminate betwixt the magnetic condition of iron, with reference to the *quantity* of any existing polarity observable therein, and the real or molecular polarity, when all the disturbances of the magnetical elements and sustaining influences are in perfect equilibrium,—conditions of things, the prevalent existence of which we shall shortly, I hope, be able to demonstrate.

But previous to this we find it desirable to revert, though at the expense of some little repetition, to principles and facts more than once referred to or described, because of their essential connection with the important practical processes we have forthwith to suggest. For these processes go the extent, not only of the restoring of an *apparently* neutral condition in any magnetic mass of malleable iron, but of the adjustment of

the magnetical disturbances of the inherent elements, or of any prevailing tendency to polarity in one direction rather than another, to a state of equilibrium whether in the magnetical or neutral condition.

The *magnetical condition*, we may in the outset remind the reader, is in no case the spontaneous effect of inherently existing powers. For the natural influence of the magnetic principle, embodied in the constitution of matter, tends to neutrality. This neutrality, however, in certain ferruginous bodies is easily disturbed, especially in soft metallic iron, by the proximity of any body in a magnetic state, or by the action of electricity, or of the partial application of heat. The quantity of disturbance varies, as we have seen, not only with the nature and power of the developing agent; but also with the quality and degree of hardness of the recipient of the inductive action. A body in the magnetic state, however, being in a state of constraint or tension, has always a tendency to return to the natural condition of neutrality. In pure soft iron, the return to its natural condition, nearly, is almost instantaneous on the removal of the disturbing cause; but in steel, the restoration to its original state is only partial, and varies, in degree, with certain relations to quality and temper.

There are different principles, however, which may serve to arrest, wholly, or in part, this natural tendency to the neutral condition. The magnetic tension may be sustained, for instance, and that with unabated energy, by the continuance in operation of the developing agency. It may be sustained *partially*, also, after the withdrawal of the disturbing power, by the completion of the magnetic circuit, as in the case of an electro-magnet of soft iron, which, after a high development of power, may retain, even after the suspension of the electrical action, a considerable degree of attractive force until the conductor, or armature, is removed. And, finally, the developed magnetism may, to a considerable extent of the original energy, be fixed, or *retained* by what, magnetically considered, may be termed, the *rigidity* of the substance of the magnet itself.

The sustaining power, in the first case referred to, it will be observed, is *extraneous*; and, being the power by which the magnetic properties are developed, is therefore perfect in operation. The sustaining power of the latter case, however, is *inherent*, and being both imperfect in itself, and capable of being acted on by slight magnetical and other influences, is therefore at once partial and, in measure and permanency, somewhat uncertain.

The inherent sustaining power possessed by iron, is comparatively feeble; though, under

certain modes of development, as we have seen, not inconsiderable. But that of steel is such as to be capable of eliciting those remarkable phenomena, which, under the form of powerful permanent magnets, have always been wont to excite so much interest and astonishment.

Whilst a magnet is free from the action of deteriorating influences *externally*, its prevalent fixed or statical condition,—as to the proportion of energy it is able to sustain out of the full measure which may have been developed under any magnetizing process,—will be found at the position in which the inherent power of rigidity ceases to give way to the inherent neutralizing force. This position, however, as our experiments on the continued or repeated effects of percussion have shown, is not, for the same bar, always determinate and unchangeable. For in these, and in various other cases, it has been found that, under any one process and instrumentality of magnetization, the maximum of power at first retained may possibly be augmented by subsequent and repeated operations. Where the magnetizing agency, indeed, is of very commanding or overwhelming power, in respect to the object acted upon, this effect will probably not be observed; but ordinarily it will be found that, if a steel bar or wire be repeatedly magnetized, under the usual means of development, and

the direction and denomination of the poles be always preserved the same, there will arise an increasing capacity for magnetic energy, with a *special tendency* to the magnetic condition in that direction of polarity, rather than in the converse. The original tendency to neutrality may thus become controlled by a new magnetic tendency in the direction in which the polarity has been prevalently elicited.

In the case of magnetical development under mechanical action, this fact was most particularly observable. Thus, in a case already referred to, in which a steel wire had been repeatedly subjected to the violence of percussion; such a disposition seemed to be produced for the magnetic influence in that special direction, that, commencing in the neutral state of the wire, with the compound process, five blows gave it a lifting power of 326 grains; when the same action, in the opposite direction of the polarity, yielded only (commencing in the neutral state) the power of sustaining about two grains! So fixed, as it were, does the tendency to the prevalent direction of the polarity sometimes become, that, in an actual experiment, a long and severe hammering, with the *south* end of the wire downward, was found only to have destroyed the previously existing magnetism without reaching the condition of a change of the poles.

Sect. II. — *On the Difference betwixt the apparent Condition of a Magnetical Body, and the Equilibrium of the inherent Magnetical Forces.*

The apparent condition of magnetism in iron and steel, as to degree of energy, has hitherto been contemplated as consisting, generally, in an equilibrium betwixt the sustaining rigidity of the metal, and the tension of the magnetic quality tending to neutralization. But *molecularly* considered, the equilibrium indicated by apparent fixidity, or the retention of a special degree of magnetic energy, may not be real; and so the *apparent non-magnetic condition* in iron or steel, may not be *an actual and general neutralization of the inherent magnetisms.*

The principle now glanced at, as possibly existing, we expect to be able to maintain as a fact in magnetic science. It pertains, perhaps, to the general phenomenon—not previously, as far as I am aware, developed—which in the Second Part of these Investigations, chapter I., we have denominated the *elasticity* of the magnetic force. This phenomenon we have shown to be peculiarly conspicuous in compound magnets, or combinations of magnetized steel plates, wherein a *portion* of the magnetic energy, suppressed by

the mutually deteriorating influences of similar poles, is recovered on the separation of the bars or plates. The extent of this elasticity, in respect to a combination of thirty cast-steel plates of a spring temper, has been shown (vol. i., p. 118,) to amount to more than one-half of the entire power possessed by the fasciculus! The effect of this suppression of elastic or recoverable power is therefore such, that the weaker plates or bars in large magnetic combinations, which, when removed, may possess some moderate and consistent polarity, might, whilst forming a part of the combination, have a *contrary* polarity (as in some cases we have proved), and thus, instead of augmenting, abstract from the general power.

But it is *another feature* of this apparently elastic property of the magnetical condition, to which the demagnetizing processes, derived from the principles now under consideration, have more special regard. And that is a certain *obtuseness of adjustment* of the antagonistic forces regulating the *quantity* of the energy sustained in a magnet; so that the statical condition, without gain or loss in essential energy, admits of a very perceptible *breadth* or *variety*. Thus, in the same magnet, having the same essential disturbance of its magnetic elements, there may appear a directive or attractive power, varying in energy in the proportion, for instance, derived

from an actual example, of 20 to 19, according as the magnetism, within the range of the quality of elasticity, may have been influenced by some extraneous force acting *favourably* or *unfavourably* on the resulting magnetic development; or, according as the last action of any extraneous magnetic influence may have been to *raise* or to *reduce* the previously existing energy.

An experimental example may at once serve to illustrate the phenomenon to which we refer, and to render more easily intelligible a subject somewhat difficult to be made clear by general description.

[28. *Exp.*]—For our illustrative experiment, a *thin* plate of cast steel, of a high *spring* temper throughout, was selected. It was two feet in length by an inch and a half in breadth. It was magnetized to saturation by means of a pair of powerful bar magnets by the process described at page 12, vol. i. The power, as tested on the deviation-board, at two feet distance from the compass, was found to be (south end) 29° 30′. The magnetized plate being now laid flat upon one of the bar magnets (which was of corresponding length and breadth) with the *same poles* in contact, had its magnetism reduced to 21° 48′, or, on the mean of four experiments, to 21° 34′.

Now in this condition, if the principle we seek to elucidate be correct, the reduction of the power, by this violence on the arrangement of the magnetical elements of the steel plate, should be *greater* than what is due to the exact balancing of the antagonistic principles determining the real magnetic energy, and, therefore, that a portion of the energy existing in a latent or *elastic* state, should be *recoverable* by any sort of vibration which might aid the more exact adjustment of the magnetical tendencies. For the ascertaining of this fact, I proceeded under the exercise of every caution, against the operation of extraneous influences, which my much experience could suggest. The plate for being specially tested, therefore, was brought, whilst resting still on the bar magnet by which its power had been reduced, into the line of the west point of the compass, but at a considerable distance from it; and then carefully removed, to avoid vibration, and carried in parallelism with the magnetic equator, to its place on the deviation-board, where its action on the needle was determined.

This being ascertained, the plate was raised a little, keeping the same parallelism with the magnetic equator, and bent and twisted (within the extent of its elasticity) in various parts of its length, with a view to aid any portion of the

magnetism which might be under constraint, to overcome such rigidity as had prevented the exact balancing of the conflicting forces within.

On trial of the effect, there was found, in accordance with theory, an *increase* in the deviating power, and that in tolerable equality in each of four experiments, giving a mean result of 21° 47′, or a *gain* of 0° 13′ by bending under circumstances (being in the plane of the magnetic equator) wherein no extraneous action from terrestrial induction could possibly influence the result.

The converse of this result was also tried in three separate experiments, by placing the plate flat upon the bar magnet with *contrary poles* contiguous—the effect of which was to raise the power of the plate beyond the mean condition of what I may term the molecular magnetic adjustment. In this case, if the principle asserted be real, we should have a *reduction* of the power (or exactly the contrary effect to what before took place) on bending or vibrating the steel plate in the plane of the magnetic equator. And this expectation was fully realized, and—as had also been anticipated—in a greater degree than in the other form of the experiment. For the mean deviating power of the plate, when thus assisted by favourable contact with the magnet in the recovery of elastic or latent energies, was found

to be 23° 3′; which power was now *reduced* by flexure, (a result accordant in nature, and converse in direction or denomination from that obtained in the other case,) to an average of 22° 27′, being to the extent of 0° 36′.

The plan of this experiment, which, with an actual magnet, I had not before tried, was noted in writing, in every leading particular before the commencement, and, as will have been seen, the results realized were in exact accordance with what had been anticipated.

Hence the principle (hereafter more fully elucidated) has, I trust, been conclusively verified,—that the *apparent* condition of iron, or steel, in respect to magnetism, is not, necessarily, its *real*, or mean statical condition. Consequently, it follows, that a bar or plate of iron, or of steel, may appear, because of its non-action on a delicate magnetic needle, not only as to its extremities but also throughout its length, to be perfectly neutral, and yet in its molecular arrangements it may be actually magnetic. That is, the molecular magnetisms may not be perfectly neutral among themselves, in one case, or proportionally sustained, in another case, but in a sort of *elastic* tension, leading to development of polarity, or change of existing polarity, on the slightest favouring influence. And such, I may

observe, must always be the condition of a regularly formed bar of iron or steel, when a feeble magnetic influence will develop one denomination of polarity and not the other; or will develop the one much stronger than the other, under like degrees of force and action.

There are many examples, analogous to this phenomenon, we may remark, in the *diverse* effects of equal forces on material bodies, reference to which may serve to elucidate, if not to explain, something of the nature of the unequal action in magnetizable bodies. Thus the needle of a compass traversing on a blunt point, or a scale-beam working on a blunt fulcrum,—each being liable to come to a condition of rest when *out* of actual equilibrium,—will be aided in a truer adjustment by any slight vibration, and in either case, too, will yield more readily, and to a greater extent of change, to the influence of a feebly acting force in the direction of the actual point of equilibrium, than in the contrary. And so also, an elastic substance which has been unduly bent in one direction and then just restored, and no more, to straightness, will, from the acquired tendency of its structure by the undue bending, yield more readily to pressure in that direction, than in the other.

As the practical equilibrium of mechanical forces affected by *friction*, therefore, may actually take place in a position considerably removed from that of the true mathematical equilibrium; so we find an analogous result in the case of the magnetical equilibrium in iron or steel.

In respect to the actual operation of this principle in *iron*, after the manner in which it has been shown to exist in steel,—my experiments on the effects of mechanical action, magnetically, on this metal, have yielded abundance of evidence.

Thus an iron bar, which may have had a high magnetic energy, being demagnetized, or *barely* neutralized by mechanical action, will yield, as we have shown, much more freely to a fresh alteration in the *direction* of its original polarity than *against* it. The inequality, indeed, in the *tendency* to change in cases of this kind has, in a special case,—that of a bar which had been reduced and nearly demagnetized from a previous strong polarity,—been found to be such, that a slight blow with the handle of the hammer, struck when the bar was held upright in the position *favourable* to a return to the original polarity, produced an alteration of seven degrees in its deflecting influence on the compass; whilst a similar blow struck when the bar was held, so as to develop a power *against* the original denomi-

nation, yielded an effect scarcely amounting to one degree!

The quality now under consideration has been thus particularly spoken of, because of its tendency, hitherto, I believe, little, if at all, regarded, to mar the precision of the results, arrived at experimentally, in some very interesting magnetical enquiries. In experiments, for instance, on the force of terrestrial magnetism, or in other departments of magnetical science in which the results are dependent on the stability of the magnetic power of the instruments employed,—the defect in molecular equilibrium, it is obvious, must be calculated to vitiate the results where the tendency in the magnetic condition to change is greater in one direction than in another: the influence, at all events, is such as to dispose the magnetic part of the apparatus to yield its undue tension to forces which, under a proper state of equilibrium, would be too weak to produce any sensible effect. In experiments, moreover, relating to the more delicate operations of the earth's inductive magnetism—the want of real molecular neutralization may greatly perplex the investigator in determining the facts, or, possibly, may essentially vitiate the conclusions apparently elicited.

SECT. III. — *The Application of the foregoing Principles to the real and molecular Demagnetization of Plates or Bars of Iron.*

PREVIOUS to these personal researches, no other process for the *effective neutralization* of incidentally acquired magnetism in iron, was known, as far as I am aware, but that of heating the mass to redness. And even this process could only be made partially available until the various tendencies of the earth's inductive action became known, in respect to differences of position. It then became obvious, that the influences which yielded to an iron bar, heated to redness, such a high degree of polarity in the position of the magnetic axis of the earth, and which *reversed* such polarity in the contrary position,—must, in the plane of the magnetic equator, develop in a slender bar or elongated plate neither the one polarity nor the other; that is, must leave the bar or plate, magnetically considered, in a neutral condition.

But this process, whilst troublesome and inconvenient, must at once alter, in regard to density and hardness, the structure of the metal, injure the appearance and surface of ordinary implements, and render utterly valueless any well fabricated instrument.

The processes we have now to describe, whilst entirely free from the palpable disadvantages of the method just referred to, are, at the same time, incomparably more ready of application, and more effective in their final results.

For the neutralizing of any incidentally acquired magnetism in bars or elongated plates of malleable iron,—so far as the magnetic condition may have been developed by mechanical action,—we find sufficient guidance in the investigations of the previous chapter. To effect this object roughly, or for all ordinary purposes, or to the extent of producing inaction on the needle of the compass when the bar or plate might be presented near to it in the plane of the magnetic equator,—the application of vibration, percussion, or other mechanical action, with due regard to *position*, will be found at once effective and simple.

But to accomplish this neutralization in the highest degree of attainable perfection, so as to be available for the most delicate investigations, attention needs to be given to the operation of principles beyond those by which changes in the magnetic condition of ferruginous bodies are generally understood to be regulated.

For the better guidance of the enquiring manipulator, I shall give the results of much personal investigation and experience in the form of

directions, or experiments, commencing with a description of the simpler processes for neutralization, as adapted for all ordinary and general purposes in magnetic researches.

[29. *Demagnetizing Process.*] — CASE I.—*For neutralizing* any incidentally-acquired polarity, in a *poker, or other bar or rod of iron.*

With a sensibly acting compass placed on a deviation-board, or, more roughly, on the surface of a table tolerably free from iron,—place the poker, or bar, to be demagnetized, in the direction of the east or west point of the compass, and a few inches distant from it, to ascertain, first of all, the nature and extent of its existing polarity. If it be a poker, the knob end being presented to the needle, will ordinarily attract the north pole,—the point, to be considered as the *marked* end, having northern polarity. If it be a plain bar of iron, let the end which indicates northern polarity be marked, or at least well observed.

Holding now the poker or bar in the hand in a *horizontal position*, east and west, strike it a few blows, sharply or moderately, according to the quantity of the magnetic energy previously indicated, upon any part of its substance. Its magnetism will now be probably found to be considerably reduced. With the knob end of the poker (yet presumed to be a south pole)

resting on the table near the compass, raise the other end, until the earth's inductive influence (acting conversely to the polarities of the bar) reduces the action of the bar to an apparently neutral condition; that is, until the needle assumes the exact meridional direction. Whilst in this position, strike the bar a single blow with a hammer, and, on presenting it again horizontally to the compass, the action will be found to be subdued, not improbably to an exact neutral condition. If, however, some southern polarity be yet indicated, repeat the process until it disappears; or if a reverse polarity should be found to be developed, a blow in the horizontal position will probably suffice for its removal. It may yet be requisite, for any nice experiments, to test the opposite end of the bar, which, whilst the other has been neutralized, may happen to retain some little polarity. If so, the sort of experiment, just suggested, but conducted cautiously as to the extent of influence used, must be repeated; the percussion being now applied *to the end next the compass*, whilst the other end is kept by the grasp of the hand as free as possible from vibration. When this end has also been neutralized, the end originally tested must be again tried, for the correcting, if required, of any excess of action on either. But in iron bars of pretty equable quality and uniformity of hardness, the neutrali-

zation of polarity in one end, will generally be effective in producing the like condition throughout the mass.

We have assumed that the first action of percussion had been sufficiently influential to provide for the neutralizing of the bar by the very moderate influences brought into action. If, however, the original polarity should happen to be very powerful, or tenaciously retentive, it may not yield to a few blows in the positions directed. In such case let a blow be struck with the hammer whilst the marked end of the bar is held *directly upward*, and, if that be not effective, let blows be *repeatedly* struck until the original polarity be not merely neutralized but sensibly and considerably reversed; then pursue the method already described until a satisfactory condition of neutrality be obtained.

Much as we have had to say in the description of the process, the actual manipulation (after due experience) is so simple and effective, that a very fair measure of neutralization can generally be effected in a few seconds of time; and rarely requires, unless much nicety be requisite, above a few minutes' attention.

It remains to be noticed, that, when any particularly nicety in the result is required, and the process has become very nearly complete,—slight taps with the *handle* of the hammer may be

sufficient; and that blows with the fist, or a *rub* on the surface with the hand, may, ultimately, be preferable to stronger mechanical action.

[30. *Demagnetizing Process.*]—CASE II.—*For demagnetizing elongated plates of sheet iron.*

To the restoring of the neutral condition of the magnetisms in *thick* plates of iron, the process just described applies; but for the demagnetizing of thin plates, capable of being bent without altering the figure, the application of flexure, instead of percussion, will often be found quite as effective and much readier.

On this principle, whilst the existing magnetism of the plate under operation is tested as above directed, the reduction of such magnetism may be generally effected in the thin plates by a slight flexure betwixt the fingers, in place of hammering, or, with an occasional blow of the plate with or against the hand, or other resisting substance. In this way, as the processes under experiment No. 21 have already indicated, the magnetism of thin plates of iron can be generally controlled, reduced or neutralized, as if magically, and in a moment of time.

Under the influence of the processes we have now described, the demagnetization of many hundreds of plates and bars of iron has been suc-

cessfully accomplished. And we may consider it, I believe, as an established principle, that for every case of magnetic development by means of simple percussion or other species of mechanical action, the like agency will be found effective for the neutralization of the polarity so developed. This *fact* of experience, indeed, as to magnetism, is one very extensively realized in other departments of art and science.

Beyond the range of operation, indeed, of mere *mechanical* action in connection with terrestrial induction, in the development of magnetic polarity,—I have found the application of percussion sufficient for neutralization. A piece of plate iron, unannealed, 18 inches long, 1 inch broad, and ·12 inch thick, was magnetized as highly as possible by a large and powerful bar magnet, with a view to the trial of the effectiveness of percussion for reducing or destroying the polarity so specially developed. And it was found that six smart blows with a hammer, whilst the plate was held in an upright position, *north pole upward*, were sufficient to disperse the previous magnetism, and that three or four more blows availed for the changing of the poles.

In another case, that of a large substantial poker of iron, which was rendered very magnetic by being laid flat upon a powerful bar magnet of the same length, the entire development of

polarity was found to yield freely to percussion, so that the poles were reversed by only two or three smart blows with the *north* end held upward.

In one instance alone, which has fallen under my own observation, percussion failed in capability of dispersing the magnetism which had been developed in an iron bar. This was in the case of an unannealed bar of round iron, three feet in length and three-quarters of an inch in thickness, which had been employed, under the action of a powerful galvanic battery sending a current through a spirally-wound coated wire in which it was enveloped, as *an electro-magnet*. A very unusual measure of residual polarity was found, after the removal of the coil, existing in the bar, which, for the purpose of applying it to use in some delicate experiments on terrestrial induction, it was necessary to have removed.

On recourse being had to the usual process of percussion, it was found, in this solitary case, to fail. A hundred blows with a hammer, with the north pole upward, scarcely reduced the polarity one-quarter; and many hundreds of additional strokes of the hammer, with the bar held in the most favourable direction for the reduction of the magnetism, (that of the magnetic axis,) causing it to vibrate and ring under the repeated action, —effected only the reduction of the power to an extent of about one-third.

In this condition, I may remark by the way, a striking example of the effects of the elastic tension, described in the preceding sections, was elicited. When the bar had, as far as possible, been reduced by the simple action of percussion, a few blows struck upon it whilst laid in the plane of the magnetic equator, produced a revulsion of the constrained force to an extent of several degrees of deviating action,—a circumstance which could alone be attributed to the elastic tension spoken of, as the position was such as to render terrestrial induction altogether neutral. The same fact was also indicated by the additional experiment of the very different effect of blows, in the two positions of the north pole upward and the converse. With the north pole upward, many blows being added to an extensive application of percussion in the same position, yielded no perceptible alteration or reduction in the magnetic condition; but a *single blow*, in an inverted position (north pole downward) actually restored the greater part of the energy which had been reduced by the former persevering application of the hammer!

The successful treatment of this obstinately retained magnetism, with a view to its reduction, will afford a special case in our demagnetizing processes, which I shall give *descriptively*, in respect to the actual manipulations, rather than *directively*, as in the former processes.

[31. *Demagnetizing Process.*]—CASE III.—*For neutralizing an iron-bar, possessing great hardness of texture or temperament, when highly and specially magnetized.*

Two processes for the reduction of this unusually fixed quality of magnetic development, presented themselves as adequate for overcoming the rigidity:—1st. The application of electro-magnetism in a direction contrary to that by which the power had been given, and in quantity so reduced as to be adapted to neutralize, rather than to change, the polarity; and, 2dly, The application, in a reversing direction, of the energy of a permanent magnet of commanding power.

This latter process, being more easily managed with the abundant apparatus at hand, was the one adopted for the special occasion. The agency required was more than adequately supplied by a straight-bar magnet of a length pretty nearly corresponding with that of the bar to be demagnetized;—though a magnet of such length, if it had not been at hand, could have been very well supplied by combining two or more bar magnets, with contrary poles in contact, in a straight-line series, of the requisite extent.

In the first trial of this agency, the iron bar was laid flat upon the magnet with similar poles coincident, with a view to the reduction of the

acquired magnetism: but the power was found to be so overwhelming as to produce a reverse polarity of as high a degree of energy as before. In its next application, therefore, a piece of board, placed betwixt the magnet and the bar, served to reduce the force of the reversing action; but it was found still to be too great. Trial was then made of the effect of greater distance, whilst the bar was held in parallelism over the magnet, with similar poles in the same direction, commencing with an interval of eight or ten inches, and then closing gradually (testing the bar at each trial) until, at the final distance of about six inches, all the existing magnetism disappeared, and a perfect neutralization was effected. The peculiar process, then, adopted for this peculiar case, proved as beautiful in the manageableness of the manipulations, as it was satisfactory in its results.

[32. *Demagnetizing Process.*] — CASE IV. — *For the thorough and molecular demagnetizing of bars and plates of iron.*

The attainment of *absolute demagnetization* in a bar of iron or steel, on the principles set forth above, consists in the bringing of the *apparent* neutrality into consistency with what we have termed the *molecular* neutrality. And this condition is known to be existing by this test;—the

development of the same exact measure of polarity, in both directions or qualities, by means of the *same degree* of magnetic force acting in contrary directions. So that, when the influence of a given measure of magnetic action producing *northern* polarity in one extremity of the bar, shall be precisely as effective (from the neutral state), under a reverse action, in afterwards developing *southern* polarity in the same extremity, —then we consider the bar to be molecularly and absolutely neutral.

For the administration of the *same degree* of magnetic force both ways, two modes occurred to me; one of them, simple *terrestrial induction*, which, for the brief time occupied in the experiment, must be considered as acting with the strictest equality of intensity; and the other, a carefully adjusted *stroke or blow* of given and uniform force, which, in its general effect, may be made to act with a sufficient degree of uniformity.

The method of applying these tests may be the most conveniently explained in the description of the process for the thorough and molecular demagnetizing of iron.

(*a*). Let the bar or elongated plate of iron to be demagnetized, be operated upon by percussion, friction, or bending, as the circumstances may

solicit or suggest, after the manner of case I. or II., until an *apparent* neutrality has been attained. If the neutralization of one extremity, however, should not have produced a like condition in the other, let gentle taps or friction be applied to the *defective* end whilst the bar is kept in the magnetic equator; and, if that should fail, then with the end very slightly raised or depressed, according as the polarity to be reduced is of the northern or southern denomination, let some slight blow be given to the same extremity. For though the effect of mechanical action, as we have elsewhere shown, is the same, as a *general fact*, wherever the bar may be struck, or in whatever direction the force may be applied, yet it is not so in *absolute strictness*. A hard piece of iron, and especially a bar of unequal hardness, may not yield, under local action, an exact uniformity in the magnetic distribution; hence the requirement, in certain nice operations, for the application of the blows in various places; and hence, too, the advantage, generally, of a vibratory action with the bar held in a string or betwixt the fingers, by which the whole mass may participate in an uniform influence.

The tendency of these operations, first on one extremity of the bar and then on the other, as occasion may require, being to produce an uniform distribution of the magnetic elements, they

should be successively repeated until the requisite neutralization is obtained.

In the case of irregular distribution of the magnetisms in an iron *plate*, susceptible of elastic flexure, the attainment of uniformity is, comparatively, easy, as one-half, or a portion of a half, of the plate, can be bent whilst the rest of it is held flat on the table, and thus a partial and local influence, from terrestrial induction, applied where needed.

(*b*). An *apparent neutralization* having been thus obtained in the bar, we proceed to *the testing of the molecular condition*. For this the influence of terrestrial induction may be first tried. Lifting the bar cautiously in the hand, without vibration or percussion, place it, for a moment, in an *upright* position, with the *marked end* (the end originally possessing northern polarity) *downward*. Then replacing it on the deviation-board, at a fixed distance from the compass (being careful not to allow the lower end to rise above the plane of the magnetic equator) observe the quantity of polarity gained by this operation. Then lifting the bar again into an upright position, with the *marked end upward*, observe, on restoring it to its place on the deviation-board, the alteration in the polarity. If the polarity derived from one of these positions be essentially different

from the other, and if, especially, similar results be obtained on re-neutralizing it in the magnetic equator and repeating the process in the *inverse* order (that is, commencing with the marked end upward); then the bar must be defective in molecular neutralization.

Again, the influence of a blow may, if deemed needful, be applied for the molecular testing. In this case, whilst the bar (after being apparently neutralized) is held upright, marked end downward, let a gentle blow with the handle of the hammer be applied, and the effect, as to the extent of magnetic development observed. Then, neutralizing this polarity by the requisite vibration in the plane of the magnetic equator, strike a similar blow on the bar whilst held upright, in an inverted position, and again observe the effect. If the polarities respectively developed be very different, we are assured that the molecular magnetisms are not in equilibrium.

(*c.*) For *the correction of this molecular tendency*, we proceed by producing a positive polarity in the contrary direction; the degree being regulated by the quantity of the molecular disturbance. If, for instance, the effect of a blow, of pretty uniform momentum, in each of the upright positions of the bar, be to produce a large development of magnetism in one position, and little or

none in the other; then it may be necessary to hammer the bar into a considerable *reverse polarity*, in order to the removal of the molecular tendency.

In cases of great molecular tension, the process of vibration in the plane of the magnetic equator, will be found the readiest test; and so long as a decided revulsion, magnetically, takes place under this action, the process of reversing the polarity should be continued.

(*d.*) *In testing by blows* in which there should be a determinate intensity, this requirement may be secured by means of a ball of ivory or metal suspended by a string of a length a little shorter than that of the bar; for if, whilst the end of the string is held in contact with the top of the bar, the ball be let swing against it from a given angle of extension, the force with which it strikes, being determined by the unvarying energy of gravitation, must be sufficiently equable.

Though the processes we have now attempted to elucidate, have required somewhat elaborate description; yet they are found in practice, after some familiarity in experience, to be so clearly guided by general laws as to leave but little embarrassment either in the modes of manipulation, or in the certainty of the results. Their

adaptation, too, under this reference to general laws and well defined principles, is found to be so general, as to extend, with but trifling differences in the manipulations, to all the varieties of malleable iron and to bars and plates of almost every variety of mass and proportions.

MAGNETICAL INVESTIGATIONS.

PART IV.

ON THE MAGNETISM OF IRON-BUILT SHIPS, WITH RELATION TO THE ACTION OF THE COMPASS, AND THE CHANGES TO WHICH THEIR MAGNETIC CONDITION IS LIABLE.

CHAPTER I.

ON THE GENERAL DISTURBING INFLUENCE OF THE IRON IN SHIPS ON THE ACTION OF THEIR COMPASSES; AND THE DEFECTIVE PRINCIPLES PREVALENTLY ADOPTED FOR THEIR ADJUSTMENT.

THE influence of terrestrial induction in rendering all iron substances magnetic, with the deflecting action of magnetic substances on the compass,—must necessarily tend to the rendering of the indications of this important instrument in ships, embodying as all ships do a considerable quantity of iron in their construction, more or less inaccurate.

Whilst the errors thus produced in the compass employed for the guidance of the navigator in ships of the old method of construction, were not ordinarily very conspicuous,—the measure of

misguidance, with its consequent danger, gained but little attention. Even after the subject had been distinctly developed by Captain Flinders, and the importance of it further demonstrated by others, so reluctantly or sceptically was it received, that some of the heaviest calamities of modern times,—in the wreck of our ships of war and merchantmen, clearly traceable to neglect or ignorance of this source of error on the indications of the compass,—did not avail to make it a matter of *general* consideration in practical navigation.

Within the early part of the present century, however, the subject had in various ways been brought before the public, so as gradually, though slowly, to become pressed on the attention of the more observant shipowners and intelligent navigators. In my own case, when engaged in adventure in regions within the Polar circle, where the anomalous action of the compass is more apparent than in lower latitudes, I was led, at a very early age, to enquire into a subject of so much importance in my profession. For to the defective indications of the compass, as observed by my intelligent father, my attention had been drawn by two or three remarkable facts,—such as the ship *lying nearer the wind*, apparently, when the wind was in one particular quarter, than when it was in the opposite direction,—the

prevalent error of the reckoning, westerly, on the homeward voyage from Greenland, etc.

The investigation of these and other anomalous indications of the compass, which was commenced in the year 1815, resulted in a paper in the Philosophical Transactions of 1819, already referred to, and ultimately led both to the determination of a table of errors for the correction of the compass courses in each ship in which I happened to sail, and to the planting of a *standard-compass* at the main-top-gallant mast-head, where it was entirely free from the magnetic action of the iron in the ship's hull.

Though the deviation of the compass had been considered and developed by a number of intelligent observers, Professor Barlow was the first to propose a scientific indicator, which might serve as a general corrective for the local attraction of the ship. Guided by his important investigations on the magnetism induced by the earth in shot and shells and other masses of iron, Mr. Barlow was led to the very elegant device of applying a corrective or indicating plate of iron to act on the compass, so that its power from terrestrial induction should, under proportional nearness and position, be made equivalent to, and by a simple process indicative of, the general force and direction of the ship's magnetism. But there was an error in the principle of this corrective, which,

though it might not be observed, or be found important, in cases where the local attraction was very feeble,—rendered it totally inadequate as a corrective for the strong magnetic action of iron-built ships. For the assumption, in the application of the correcting-plate, (altogether incompatible, it will be observed, with the principles developed in the foregoing chapters) was, that all the magnetic forces in the ship, by which the deviation of the compass was occasioned, were equally as transient and mobile as the inductive influence of the earth on the soft-iron plate.

The extensive and increasing substitution of *iron* for timber in the construction of ships, however, where the disturbing action became such that no place on the deck could be found in which a compass might indicate the direction of the ship's head in any degree of consistency with truth,—constrained still further and more special attention to a subject involving, so deeply and essentially, the safety of life and property.

Professor Airy who, along with other men of science, had directed his attention to this important subject, was the first, I believe, to investigate, experimentally and mathematically, the actual condition and influence of the magnetisms in an iron-built ship, and to analyse the qualities of such magnetisms so far as these were indicated by the changes observed on swinging the ship.

In his experiments on board the iron-built steam ship, the Rainbow, Mr. Airy found, in accordance with the principles elucidated in chapter III, part III, that some other quality of magnetism, besides that simply due to ordinary terrestrial induction, was not only present but particularly influential. The proportions, too, in which the transient and the partially enduring magnetisms, as effecting the compass in this vessel, respectively existed, were carefully enquired into, and found to place the latter in a highly dominant position. Hence, in the concluding observations of his paper in the Philosophical Transactions for 1839, comprising the results of observations and experiments, very elaborately and ably discussed, Mr. Airy states, that "the most remarkable result, in a scientific view, is the great intensity of the permanent magnetism of the malleable iron of which the ship is composed. It appears, however," he adds, "that almost every plate of rolled iron is intensely magnetic."

With the view of neutralizing, as to their action on the steering-compass, these disturbing influences, Mr. Airy varies the method of Mr. Barlow, and adds to it a new magnetic corrective. The principle on which the adjustment is founded is—that "the combined powers of the independent magnetism of the ship and the magnetism produced by terrestrial action," may be corrected

"by the introduction of antagonist magnets and masses of soft iron," and so corrected as to "be made perfect." For the correction of the former influence, two permanent bar-magnets are proposed to be employed; and for the latter, a long box filled with iron chain, with its end towards the compass, as more likely to be devoid of "permanent magnetism" — "from which no plate iron," as Mr. Airy supposes, "is free."

These contrivances to meet the sources of deviating action, elegant and effective, to the extent of the principles *supposed* to be in operation, as they are, can only avail for a safe and useful end, so far as they embrace *the whole* of the actuating causes. If they do not embrace the entire influences, their operation must be defective, and the compass indications, under a change of circumstances or place, may be quite untrue. And though the compensations may be in considerable degree effective in proximate magnetic latitudes to that in which the adjustments are made, yet if the converse be the case in very different regions, or in a heeling position of the ship,—then, by the delusive confidence thus given to the navigator in his compasses, the *supposed corrective* may the more fatally betray!

The extremely disturbing action of the *material* of iron-built ships on the compass, and its bear-

ing on their safety in distant voyages, yield—now when this class of vessels has become so very numerous—a high degree of importance to enquiries concerning the principles which regulate the distribution and changes of the magnetic condition of such vessels.

Researches heretofore made—not only as to those we have referred to but as to a variety of other scientific investigations on the subject—have served, along with much admirable and elaborate discussion of the results, to elicit so much information, as, within the scope and plan of the special investigations, to leave comparatively nothing essential beyond. Thus, in regard to the modes of determining the errors of the compass for vessels in a quiescent condition, or whilst being quietly swung in dock or harbour; the mathematical processes for obtaining tables of compass deviations from a series, or limited portion of a series, of observations; the adjustment of any table of observed deviations to changes in magnetic latitude, so far as these changes have been contemplated as operating,*—have been effected with so much science, as, within the range of the principles contemplated, might have served

* The "Instructions for the Computation of a Table of Deviations," etc., by Mr. Archibald Smith, may be particularly noticed in respect to the processes referred to, as at once complete, elegant, and simple.

to place the intelligent navigator, in an iron-built ship, in as favourable a position, as if no insidious influence was in existence to disturb the action of his compass.

But a most important and extensive influence, necessarily and universally prevalent in iron-built sea-going vessels (as we expect to be able to demonstrate) which must be productive of rapid, and, sometimes, astonishing *changes*, is not included—except partially and vaguely—in the consideration of the principles from whence these practical correctives and processes have been derived. It is to the nature and operation of these *extra principles* affecting the magnetic condition and its changes, in iron-built ships, to which the Investigations of this Fourth Part of our work mainly and essentially refer. And, I am led to believe, that the *changes* produced must affect the action of the compass on ship-board, in a manner very different, both as to variety and quantity, from what has at all been contemplated, either in the modes of obtaining tables of errors for the local deviations, or adjusting antagonistic correctives for the ship's magnetic influence.

If the ship's magnetism, indeed, had consisted merely of the transient and mobile quality of terrestrial induction,—then had Mr. Barlow's elegant and scientific application of the correct-

ing iron-plate provided for every thing essentially needed for safe navigation. Or if the ship's magnetism had consisted truly of *two qualities*, only,—that terrestrially induced, and that usually denominated fixed or permanent,—the method of Mr. Airy of combining a mass of malleable iron, for the neutralizing of the former, with permanent bar-magnets for the correction of the latter, might, in ordinary cases, have proved as effective, as the device was scientific and beautiful.

But if the magnetic qualities essentially pertaining to iron-built ships, as we expect to prove, be of a more mixed and varied nature; if there is one quality spontaneously changeable under every change in the direction of the earth's action; another quality which, *whilst sustained by the congenial action of the terrestrial magnetism*, (but whilst so sustained only) has the effect of a permanent or fixed condition; and another powerful quality, developed by mechanical action aiding terrestrial magnetism, which may be modified or obliterated by other mechanical violence, under diverse circumstances of terrestrial influence,—then it will follow, that the methods hitherto adopted for the correction of the ship's steering compass, depending on elements derived solely from the quiet swinging of the ship, must be imperfect, and in their application (except in a partial and inferior measure) fallacious.

The results of the foregoing researches, I believe, will, on the strictest grounds of inductive science, authorize the conclusion, that the existence and operation of principles which we have now hypothetically suggested, are actual scientific truths. For even the series of *rudimentary experiments* in part III. (sect. ii. of chap. iii.), on the effects of percussion in augmenting, reversing, modifying, and neutralizing the magnetism of an iron bar; with the corresponding results, sect. iv., on the magnetic changes in elongated iron plates produced by mere flexure, are sufficient, I think, (independent of the great body of analogous indications,) to prove the existence of the diverse and distinctive magnetic qualities, described in our *Definitions*, page 129;—qualities, no doubt, generally elicited in iron bodies when subjected, under corresponding changes of position, to mechanical vibrations or violence. Under the operation, therefore, of these augmenting and modifying influences, the magnetical condition of iron-built ships must, in accordance with our hypothetically stated principles, be essentially unfixed and changeable.

The influence of percussion and other mechanical action in augmenting, as we have seen, the efficacy of terrestrial induction in developing the magnetic condition in iron, must, it is obvious, operate most powerfully during the construc-

tion of iron-built ships. For each plate of iron attached to the structure becomes, individually, the recipient of percussive action on a system so elaborate, as, during the process of rivetting around its entire margin, must be calculated to elicit a very high degree of magnetic energy. Whilst every plate in its turn thus becomes the subject of separate mechanical violence, and whilst the magnetic development of many of the plates is furthermore solicited by heating and bending,—the various and elaborate applications of the hammer to all parts of the structure as it advances from keel to gunwale, or from stem to stern, must tend at once to yield an unity of magnetic relation throughout the entire ship, and to give to that unity the highest degree of energy of the quality which we have defined *retentive magnetism*, which terrestrial induction, aided by mechanical violence, is capable of developing.

Now it is in this condition of things, where the retentive magnetism is at a maximum, and the polarities of the general magnetism *apparently* fixed and determinate, that the processes for adjusting the compass or ascertaining its errors are usually, in the first instance, proceeded with. And the large measure of *apparent* fixidity, in the forms of retentive magnetism and magnetism terrestrially sustained (pages 129 and 130)—the proportion of the ship's magnetism not yielding to

a quiet unvibratory change of position—being prevalently assumed to be *real*, is, under this assumption, adopted as the basis of a general compass adjustment almost regardless of circumstances and conditions which may act adversely on the primarily existing magnetisms, and may subject the magnetic condition of the sea-going ship to perpetual changes.

The method, therefore, as at present adopted, of finding the local attraction on the ship being quietly swung round, and taking the deviations thus determined for *general guidance*—notwithstanding the various modifying influences of vibratory mechanical action under changes of the ship's position,—must certainly be defective and erroneous; whilst the process for adjusting the *changeable* action of the compass by antagonistic magnets of *unvarying energy* must be still more delusive and dangerous.

CHAPTER II.

ON THE EFFECTS OF PERCUSSION ON HEAVY PLATES OF ROLLED IRON ANALOGOUS TO THE MATERIAL USED, IN THE PLACE OF PLANKING, IN THE CONSTRUCTION OF IRON-BUILT SHIPS.

An objection, it is obvious, might not unreasonably be raised, against the application of the results of experiments on the magnetical conditions and changes in iron of the *bar* form, (to which our researches have been most specially directed) to the case of iron-built ships, in which the surface of the entire structure presents the prevailing aspect of a continuous sheet, on each side, extending from keel to gunwale, and from stem to stern. It might be said—"Your results of experiments on iron bars may be all true and, as to *bars*, quite conclusive; but iron ships are built chiefly of rolled-iron plates, and such plates, may, under their peculiar mode of fabrication, possess peculiar and more permanent magnetic qualities."

Though not built actually of bars, yet iron ships, we may observe, have, in their construction, a large body of iron of the nature of bars. The

whole of their angle-irons, or ribs, their stem and stern-post, keel and beams, partake essentially of the nature of bars; and these constitute no inconsiderable proportion in the mass of iron embodied in the structure of such ships. But besides the proportion of iron bearing strict analogy with the kinds employed in the foregoing researches, I could myself have no doubt but that *sheet-iron* of every description and form, must be subject, under mechanical action, to the same general laws of magnetical development and change.

For the determination of this confidently anticipated fact, I undertook, several years ago, a series of experiments on the effects of percussion on a particular quality and form of iron, correspondent, in every essential particular, with that which constitutes almost the entire exterior surface of iron-built ships.

My investigations on this kind of rolled-iron plates, were made (June 1847,) at the place of their fabrication,—the Bowling Ironworks, Bradford. And by the accommodation kindly given me by the manager, Mr. Hartop, and with the personal assistance of the master of the forge, Mr. Henry Lea with his sons, I was enabled to conduct my series of experiments to the full extent I required, and to the attainment of very satisfactory conclusions.

Amid the various lots and kinds of iron in

store on the premises, I found several considerable collections of heavy rolled plates, from out of which, in a particular set standing on their ends, I selected a single plate which I deemed well adapted for my proposed experiments. It was five-sixteenths of an inch in thickness, and comprised an extent of fifteen square feet of surface,—being five feet in length and three in breadth.

Three different enquiries were contemplated, which, with this and other plates at command, I expected to be able to resolve:*—1. Whether *rolled iron* derives from the process of fabrication any extraordinary or peculiar measure of magnetic development?—2. Whether the magnetism incidentally elicited in rolled-iron plates is, like that in bar iron, changeable and controllable, under the requisite changes of position, by vibratory or percussive action?—3. Whether iron plates are more susceptible of the magnetic condition, or more tenacious in its retention, in the direction in which they are rolled, than transversely across the grain?—The experiments undertaken with a view to the resolving of these several enquiries, we give in separate sections.

* These enquiries were suggested by deductions or suppositions, with which my personal researches were completely at variance, derived from the examination of the iron-built ship, the Rainbow, by Mr. Airy.

SECT. I.—*Whether rolled Iron derives, from the process of fabrication, any extraordinary or peculiar measure of Magnetic Development?*

FROM theory, I may remark, it was rather to be inferred, that the condition to be enquired into could hardly be elicited. For the *manner* of fabrication,—so far as the *last* and most influential processes magnetically go,—is more calculated, on the principles heretofore determined, to neutralize than to develop any special polarity. The rolling, for instance, is mainly carried on in or near the plane of the horizon, and, therefore, but little calculated to develop any considerable magnetic energy; whilst the process of *flattening*, by beating the yet red-hot plates with heavy mallets whilst lying flat on the floor or ground, is still further calculated to reduce, rather than to increase, any previously existing condition of magnetic intensity. And, it may be added, the concluding process of trimming the edges of the iron plates, when cold, under the operation of the shears, must furthermore tend, since the position of both shears and plates is horizontal, to bring the magnetic condition, still further, into a subdued or moderate degree of energy.

Our actual experiments did not fail to substantiate these anticipations. Such trials on heavy plate-iron, as I thought it necessary to

make, indicated the acquisition of but very moderate measures of magnetic development beyond the quantities simply due to the present action of terrestrial induction. It will be sufficient for our object to particularize, only, the magnetic state of the plate selected for these experiments.

For this trial, as well as for general convenience in the subsequent researches, the plate was taken into an adjoining office,—having first had its position, as it stood against the wall, marked on the ends,—U indicating the upper, and L the lower end. The compass was adjusted on a platform five feet high, so as to be on a level with the top of the plate when placed upright, and standing on one of its narrowest edges. Two cross lines, in the direction of the cardinal points of the compass, were drawn on the floor with chalk, for the readier adjustment of the lower edge of the plate in either the north and south, or east and west direction. The distance from the plate at which the deviations were observed was 13·5 inches,—a distance somewhat incidentally assumed at the commencement, but found convenient afterwards to be adhered to. These, as to a considerable portion of the series of experiments, were general arrangements; but we now proceed to the mention of the results on the special case before us.

The plate, in order to our first enquiry, was placed upright, U end upward, with its lower edge on the east and west line—that is, the plane of the plate being at right angles to that of the magnetic meridian. The compass was in the same straight line; to which the nearest upper corner of the plate was proximate. The magnetic force of that corner being determined, the plate was carefully and smoothly slewed round for the trial of the other corner. Their mean deviation was found to be 38°,—attractive of the north pole of the needle.

Inverting the plate, as quietly as possible, so as to place the end L upward, a second set of deviations was obtaining, which gave a mean of 29° 30′,—also attractive of the north pole.

These results, indicating a difference in the magnetic action of the two ends of the plate of 8° 30′, gave a proportion only of 4° 15′ of the quality of *retentive* magnetism, whilst that derived spontaneously from terrestrial induction was (roughly estimated) no less than 33° 45′. Or, comparing the tangents of the deviations, we find the inductive power from the earth, exceeding the more fixed quality (which had been assumed by some investigators as very dominant), in the ratio of about nine to one.

SECT. II.—*Whether the Magnetism incidentally elicited in rolled-iron Plates, is, like that in Bar Iron, changeable and controllable, under the requisite changes of Position, by vibratory or percussive Action?*

1. THE influence of percussion on the magnetic condition of the plate, in the position last adopted (U end downward), was next tried, and the effect was found to be consistent with all our former experiments. Three moderate blows with a hammer of three pounds weight, being struck on the upper side, augmented the deviating action of the plate from 29° 30′ to 37°, and six more blows to 41°,—thus passing the neutral state indicated by 33° 45′ deviating vertical action, and changing the magnetic condition of the plate to the opposite polarity.

In order to verify this result, the plate was turned with the U end upwards, when that end, which had originally a dominant magnetic action, now only produced a deflection of the needle to the extent of 25°. A single blow of the hammer, however, served to add 6° to the previous influence; whilst six more blows availed amply to restore its original energy.

2. Changing the position of the plate (whilst standing upright on its end) into the line or plane

of the magnetic meridian,—the changes effected by percussion were determined by the deviating action of the upper end, when the compass was placed *west* of the *middle* of the plate, at the same distance as before. A larger mass of iron being now proximate to the compass than the former position afforded, the deviations were, in consequence, greatly augmented. Thus, with L end downward, on the new method of trial, the deviation was 63°, and, on the inversion of the plate, 49°.

In the latter state, a dozen blows with a *wooden mallet* produced an increase in the deviating action of the L end, to 55°, and a second dozen to 58°.

On reversing the plate, the deviating action of the middle of the upper end was found to be 56°, attractive of the north pole of the needle, which was increased to 61° by a dozen blows of the mallet on the face of the iron. This deflection was only increased 1° by a dozen more blows of the mallet and as many with the hammer.

Reversing the plate again, the *effect of more powerful percussion*, by blows with two hammers struck simultaneously on the opposite sides, was next tried. Fifty blows, on this system, served to increase the former maximum deviation of 62° to 67°.

3. With the plate resting on its *longest edge* on the north and south line,—the changes effected by percussion in the magnetic force of its shortest diameter, were tested experimentally. The results were in all respects, except as to the amount of the deviations, consistent with those obtained with the plate on an end. The power of both edges was very similar; the mean induced polarity, which was 45°, being increased to 52°, or reversed on change of the edges upward, to a like amount, by the ordinary quantity of percussive action.

4. Trial of the effects of percussion on the iron plate *when laid* flat on the floor, was next made. Its longest diameter, in this case, ranged east and west, and the compass was placed on the floor eastward of it, (proximate to the *middle* of the narrow extremity) at the distance of 13·5 inches, as usual. The deviating action, derived from the former hammering in the upright position, was found, in south polarity, to be 8°, which, after a number of smart blows with the hammer, was reduced to 5°. Raising, then, the western end of the plate to an angle of about 20°, or until the needle stood about the zero, (after the manner recommended at page 221 for the neutralizing of any tenaciously retained magnetism in iron-bars)—the hammer was again applied,

when, after a very few blows, the deviating power disappeared; the plate, as to its general magnetic condition, being neutral. For on slewing the plate with its longer axis north and south, and presenting the compass to the middle of the longest side, eastward, this side, also, was found to be devoid of magnetic action.

5. The effects of percussion when the plate was on edge, were further tested by the deviations obtained with the plate laid flat, and the compass proximate, eastward, to the middle of the edge which had been downward. After sixteen blows with the hammer, some on the upward edge and some on the sides, when the short axis of the plate was upright, it acquired a deviating power (as tested in the horizontal plane) of 10°,—the effect of the *retentive* magnetism.

On inverting the plate and hammering it, as before, with the longer edge again above, the magnetic condition was reversed, and a deflecting power (tested when laid flat,) of 6° in residual magnetism elicited.

Whilst the plate, thus endued with retentive magnetism, was laid flat on the floor, a very small quantity of percussion served to render it neutral.

SECT. III.—*Whether Iron Plates are more susceptible of the Magnetical Condition, or more tenacious in its Retention, in the direction in which they are rolled, than transversely across the Grain?*

WITH a view to this enquiry, to which I was guided by a suggestion of Mr. Airy, I was allowed to have the iron plate employed in the foregoing experiments of this chapter placed in contact with the shears, and a portion cut off, so as to leave an exact square of nine superficial feet, or three feet length of side. The several edges of the plate were previously distinguished by numerals; 1, 2 being those terminating the direction of the rolling, from whence a portion had been cut off, and 3, 4 the edges in the transverse direction, which retained their original width.

1. The first object was to neutralize the existing magnetism, which,—on testing it horizontally on the floor, with the compass, eastward, 13·5 inches distance from the middle of the edge, No. 1,—was found to be so considerable as to produce a deflection of 7° on the needle. Six or eight blows being struck on the flat surface with the hammer, whilst it remained undisturbed as to position, caused the deviation to recede to 3°.

Slewing the plate so far as to bring the next edge, No. 2, proximate to the compass, the entire magnetic development disappeared after four more blows of the hammer; for the neutralization happened to be so complete that none of the four edges, when successively tested by the compass, produced any material disturbance in the proper position of the needle.

2. The simple effect of terrestrial induction was now tried whilst the plate was set perpendicularly on edge, in the line of the magnetic meridian, with the compass opposite the middle of the lower edge, eastward of it, and at 13·5 inches distance.

The mean deviating action of the edges 1 and 2, tried in succession, indicative of the magnetic development *in the direction of the grain*, was found to be 38°; and the mean of sides 3 and 4, *transverse to the grain*, 37°. Thus the mean effect of the earth's magnetism, unsolicited by mechanical vibration, was, on this square plate, represented by a deviation of 37° 30′, from which the special deviation of none of the edges appeared to differ beyond, perhaps, a twentieth part of the whole.

3. The next experiment was the trial of the magnetic development of the several edges, by a

specific quantity of percussion whilst the plate was held, as before, in an upright position, on edge.

Six blows being struck with the hammer on the top, with the edge No. 4 upward, gave a deviation of 43°, which was increased, by six more blows on the side, to 45°. Another experiment gave 46°,—the maximum magnetic energy elicited, with the axis of polarity *across the grain*. On quietly inverting the plate to avoid concussion, the simple effect of terrestrial induction was found to be reduced, from the average of 37° 30′, to 31° 30′. But six blows on the top increased the action of the edge, No. 3 to 42°, and six more blows on the flat side to 46°, —the same maximum as before.

A similar course of percussion, in respect to position, was adopted with the edges No. 1 and 2 alternately upward, when the maximum polarity of No. 1 proved to be a deviating action of 47°, and of No. 2 of 46°.

The deviations, in the two last series of experiments, observed under similar circumstances, and after a similar quantity of mechanical violence, are, as will be seen, in remarkable conformity with each other. The spontaneous influence of the earth's induction in the direction of the grain of the iron and across it, was so

nearly similar as to leave it doubtful to what cause to ascribe the small difference: and the effects of percussion, whatever side of the plate might be upward, were singularly coincident.

Thus commencing with the magnetisms neutral, or in a state of polarity converse to that of terrestrial action, it was found, that *six blows* on the upper edge of the plate developed, when the direction of the grain was up and down, a deviating power of 43° and 42°; and when the grain was horizontal of 43°, 42°, and 43°.

Again,—after a *second series of six blows* on the upper edge of the iron, a power of influencing the needle was found to be developed (taking the result of two sets of experiments), to the extent of 45°, 46°, 46° and 46°, when the polarity was directed *across* the grain; and of 47° and 46°, when it was elicited in the direction of the grain.

Sect. IV.—*General Conclusions in respect to the foregoing Enquiries.*

Though the foregoing experiments may not be held as sufficient,—because of their limitation to a single plate of iron, and because of the very moderate quantity of percussive action employed,—for the establishment of general laws; yet they will subserve our leading object, I think, so far as may justify the following conclusions:—

1. That rolled or plate iron, as a denomination, is not necessarily magnetic in any extraordinary or peculiar degree,—the plate examined evincing only a very moderate measure of existing magnetism.

2. That the measure of existing magnetism in such rolled plates is not permanent, but of the quality we have designated *retentive*.

3. That the magnetism of rolled-iron plates, incidentally acquired, is so little fixed, that a smart blow or two with a hammer, when the plate is in a position converse to that of the earth's inductive influence, is sufficient to destroy the polarity; and that a few blows, in a proper position, is sufficient to enable the earth's induction to reverse the original polarity, and that with an equal, or even augmented, degree of intensity.

4. That vibratory blows, such as those by a wooden mallet, with the plate laid flat on the ground, or in a position near the plane of the magnetic equator, are adequate to the obliteration, unless in very slight measure, of ordinary degrees of magnetism previously exhibited.

5. That there does not appear to be any appre-

ciable difference in the capacity of rolled-iron plates for magnetism, whether the magnetism be developed in the direction of the grain or fibre of the iron, or across it; nor does there appear to be any difference, as to the effects of a given measure of mechanical action in aiding the development of polarity under the earth's induction, whatever may be the *direction* across the plate in which the magnetism may be developed.

6. That the results obtained by means of the particular iron-plate, herein subjected to experiment, are *favourably* or satisfactorily applicable, as to the leading design of the investigation, to the case of iron-built ships; since the iron-plates employed for ship-building, whilst similar in general quality and nature, are of a somewhat *softer* kind than that employed in our experiments, and the magnetism therein, therefore, still more mobile, or more easily developed or changed, than in the specimen we employed.

7. That seeing, now, the two forms of malleable iron of which the structure of iron-built ships is mainly composed,—viz. the general forms of *bars* and *plates*,—are both subject to a corresponding magnetic augmentation, reversion of polarity, alteration of energy, or neutralization,

under the influence of terrestrial induction, duly varied in its direction, and aided in its operation by mechanical violence,—it hence may be reasonably inferred, that the magnetic condition of the general body of iron-built ships, must, under a due application of mechanical violence in connection with the required changes in the earth's magnetic action, be subject to change both in force and distribution in accordance with the general laws.

8. Finally, it should be noted, that we do not hold it as *determined*, that the changes produced on the magnetism of heavy plate-iron in our experiments, must necessarily follow *with like facility* in the *special* case of iron-built ships, where the riveting of plate upon plate and series upon series must tend to a very high degree of magnetic development: on the contrary, it might be reasonably questioned, whether a degree of fixedness may not improbably be given to the texture of the iron, by this process of fabrication, such as to prevent the magnetic development from yielding very *materially* (even under circumstances of position favourable to change) to slight vibratory action, or moderate applications of percussion?

CHAPTER III.

ON THE SPECIAL CONDITION OF THE MAGNETISMS IN IRON SHIPS, AS DEVELOPED AND DISTRIBUTED IN THE PROGRESS OF THEIR CONSTRUCTION.

SECT. I.—*Theoretical Exposition.*

IF a ship could be built of iron entirely in a neutral or non-magnetic state, and the iron put together without percussion, bending, or other mechanical violence,—the magnetic condition of the fabric would be found, necessarily, in strict and simple accordance with the laws of action of terrestrial induction. The distribution of the magnetisms, in this case, would have general agreement (modified by the irregularities of mass and form in different parts of the ship) with the results obtained by Professor Barlow in his experiments on the magnetism of a cannon, and with what we have endeavoured in briefest terms to describe in Result No. 2, at the conclusion of our second chapter on Terrestrial Induction.

If, now, when the suppositious structure was completed the entire surface and frame-work,

whilst yet unmoved and resting on the original blocks, should be subjected to a severe and long-continued hammering,—the effect, magnetically, would be *not* to alter the general distribution and polarities, but to strengthen the intensity of the development. Whilst, therefore, the primary influence of terrestrial induction in the form of *magnetism of position* would remain, that influence would be confirmed, as it were, and strengthened, by the acquisition of the new property of *retentive magnetism*. And, whilst in the main body of the structure, the direction of the polarities and the position of the equatorial plane, would be respectively proximate to, if not coincident with, the axis and equator of the earth's magnetism,—the extent of development, and the intensity of the magnetic energy, would have relation, on the one part to the qualities, extension, and mass of iron in the ship, and, on the other part, to the quantity of mechanical violence to which the mass of metal might have been subjected.

Every iron-built ship, therefore,—because of the unlimited variety both in the quantity and distribution of the metal embodied therein, as well as in the position of the structure with reference to the earth's inductive action whilst building,—obtains a *special individuality* in respect to its magnetic condition. Hence two ships built on the

same blocks, with the same lines and dimensions, and the same exact set of moulds, would, along with a *general correspondence* in the magnetic distribution, be found *dissimilar* in their action on compasses in the same relative position; for the unavoidable differences in the substance, temperament, or position of the vast number of pieces of iron employed in the structure, with the varieties in the measure of heating the plates for bending, and in the quantity of percussion in putting them together, would necessarily occasion some difference in the magnetic action on compasses relatively situated, in the two vessels. But these varieties in the magnetic distribution in different ships must be greatly augmented, and the anticipation of their peculiar operation in each ship greatly perplexed, by the diversity in the earth's inductive action on ships constructed with their keels on magnetic lines of endless variety in direction.

In the magnetical condition of any particular ship, we may discriminate the operation of two qualities in the resulting action on the compasses, —that of the *general distribution* of magnetic influences affecting the compasses, under specific laws, in all positions, and that of *special influences* derived from the proximate or dominant action of particular masses of iron. These qualities are, of course, combined, in the general resultant of

magnetic forces acting, disturbingly, on a compass in any fixed position; and they are both embodied in the determinations, for such compass, of the circle of errors, whilst the ship is swung round, due to the "local attraction."

The *general* influence of a ship's magnetic action,—as suggested in my paper, "On the Anomaly in the Variation of the Magnetic Needle as observed on Shipboard," (Philosophical Transactions for 1819,)—results in the production of "a kind of *magnetic focus of attraction;* the principal south pole of which being upward," in these high magnetic latitudes, acts attractively on the north pole of the compass, and produces that anomaly or deviation in the direction of the needle from which scarcely any ship is entirely free. And the *special* influence, as in the same paper was specified, results from the accidental proximity of any large mass of wrought iron, when the compass "foregoes, in a great measure, the general influence of the focus of attraction, and submits to that of the nearer body of iron."

Thus the general distribution of the magnetisms in an iron-built ship, becomes infinitely varied and modified, as to the compass action, by means of proximate *local* influences. But these local influences may not always operate in *exaggeration* of the general deviating action; for in certain cases, by reason of appropriateness of

relative position, they may act *correctively* on the general forces acting disturbingly on the right direction of the needle. Thus, for instance, whilst a compass on the quarter-deck in an iron-built ship, may, from the energy of the general focus of attraction in drawing the north pole *forward*, have very large errors; another compass placed farther aft, may, from the proximate influence of the iron *stern-post*, with its southern polarity above, have the deflected north pole so strongly attracted in a converse direction to that of the general action, as to be compensated in its deviations and cause the direction of the needle to give correct indications. And this is a condition of things which Mr. James R. Napier, of Glasgow, in his researches on this important subject, has actually realized.

With all these varying and disturbing influences, however, *within* the vessel, the general distribution must follow determinate laws, the effects of which, we apprehend, in positions sufficiently remote from *special* local influences, should be indicated *externally*, by satisfactory and consistent magnetic action. The general effects of these laws, *theoretically*, may be compendiously illustrated by considering what the diverse action of terrestrial induction should be in the case of several iron ships of similar form and construction, and with a symmetrical dispo-

sition of the iron embodied in their structure,—on being built in various positions as to the line of the keel and direction of the head. We will suppose, for example, *four* such vessels to be built, with their heads directed respectively (after the plan of the annexed figures) to the four cardinal points of the compass, S. E. N. W.

FIG. 14. Head S.

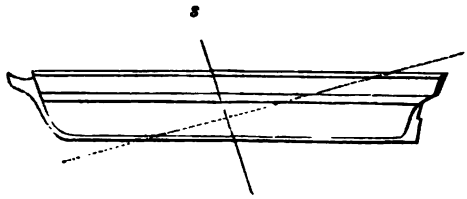
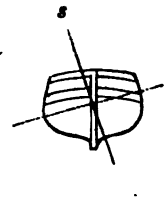


FIG. 15. E.



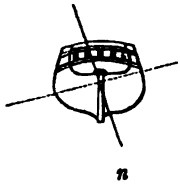


FIG. 17. W.

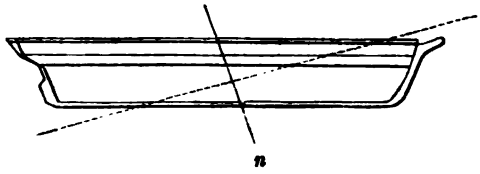


FIG. 16. N.

In the case of the first of these vessels, fig. 14, with the head towards the *south*, the general magnetic distribution should cast the *equatorial plane*, or the plane dividing the northern and southern polarities, in a horizontal position *transversely*, and rising up to the deck, or near the deck, at the stern. The *axis* of polarity, in this case, should be found inclining *forward* at the

upper, or southern extremity, in the vertical plane connecting the stem and stern-post.

In the second case supposed, that of the ship with her head to the *east*, the equatorial plane would pass obliquely across her width, rising pretty high up on the *port* side and being depressed towards the bilge on the *starboard* side, —so as to give a stronger magnetic action starboard-wise, on compasses on deck than towards the opposite side. The axis of polarity, too, would incline to starboard.

In the third case, with the head *northward*, the equatorial plane would fall down to the keel of the ship, abaft, if not below it, so as to yield, by the mass of iron above this plane at the stern, a very high degree of magnetic action to the southern, or upper polarity, of that region of the vessel. The axis of polarity, here, should be in the upright plane of the keel, raking aft, after the manner of the masts of a clipper-schooner.

And, finally, in the case of the ship's head *westward*, we shall have the equatorial plane inclined to the port side, so as to produce a dominant southern polarity on deck on that side. The axis of polarity, it would follow, should be in the direction of a ship's masts when heeling greatly to port.

Such, I apprehend—were all the circumstances

correspondent, and the iron employed in the construction of each ship symmetrically arranged on the two sides—should be the nature of the general magnetic distribution, with its peculiar diversities of arrangement, in the several cases supposed. And, under the intensely augmenting action of the mechanical violence employed in the construction of these ships, the characteristic arrangement of the magnetic forces belonging to each of the cases would be expected to be found in a certain degree fixed; that is, a degree of dominancy would probably be found to have been given to the *retentive* quality such as (under subsequent changes of position after being launched) might yield a measure of *apparent fixidity* to the magnetisms, sufficient to obtain for each, otherwise similar vessels, its special and characteristic circle of deviating action on the compass.

This assumed adherence of the magnetic poles of any iron ship to the peculiar position of their original development, until changed or modified by some adequately disturbing influence, might perhaps be questioned on the ground of the supposed difficulty of fixing polarity in surfaces, like the curved expanse of a ship's bilge, not having any terminal point for the confinement or special determination of the magnetic concentration. For, from the failure of many magneticians in the attempt to give a due degree of attractive

energy to a circular or annular magnet, it has been popularly assumed, I believe, that, in such forms, the polarity must be essentially unfixed; and if so, it might be legitimately questioned whether a special concentration of magnetic action originally developed in the curvature of a ship's bilge or floor, could be sustained, when the ship should be swung round, in any degree of retentiveness?

A simple experiment, made on a hoop of malleable iron, however, sufficed to show that with all the susceptibility of its magnetic condition to change under mechanical violence, a strong polarity could be easily developed in any required part of it; which polarity remained characteristically dominant in all positions of the hoop so long as it was kept from percussive action, or other form of mechanical violence.

[33. *Exp.*]—The practicability of fixing polarity, retentively, in an annular form of malleable iron, in any required position, and of varying the position of the poles at pleasure, was determined experimentally on a thin broad hoop of that metal. Holding the hoop, after being carefully demagnetized, in the vertical plane of the magnetic meridian, and striking it moderately in various parts of its surface with a hammer, the lower edge,—when tested with the hoop laid flat

on the table, westward of the compass—was found to be a strong north pole, the place which had been in the line of the dipping-needle passing through the centre of the hoop, being the most highly so. With the hoop exactly inverted, a very little percussion served to reverse the polarity and to produce, as before, retentive poles, in the positions determined by the direction of the earth's magnetic axis. And with the hoop held in the same vertical plane, the quadrature of the former summits being alternately upward, the polarities were correspondently changed, and, according to the usual extent of retentiveness, fixed as before. Not, indeed, that the magnetic action in any of these cases could be said to be concentrated in a precise point; but, as shown in our account of experiment No. 15, on the magnetism of an iron-hoop (page 101), elicited in somewhat broad and diffuse poles.

SECT. II.—*Experimental Investigation of the Magnetic Development in an Iron-built Frigate —the Simoom.*

TOWARDS the testing of these theoretical views of the special condition of the magnetisms in iron-built ships, as distributed and developed in the progress of their construction,—I have had but few opportunities of making satisfactory experiments on the actual case of such description of

vessels. One such case, however, and the very first I investigated, is too important to be passed over without particular notice and description.

After the foregoing investigations and deductions had, as to their substance and general results, been for some time completed,—I had a most favourable opportunity of verifying some of the leading principles to which I had been guided, by experiments on the actual magnetic condition of an iron-steamship of the largest class, whilst yet on the stocks.

The ship referred to—the Simoom—designed for her Majesty's service, was in progress of construction in the yard of Robert Napier, Esq., on the Clyde, when I happened to be on a visit at Pollock, in the neighbourhood of Glasgow. From stem to stern, over all, the length of this ship, I was informed, was 250 feet. The extreme breadth was 41 feet 6 inches; the depth 34 feet; the capacity about 2000 tons. The sheet iron, forming the exterior shell of the ship, was from one inch, below, to three-quarters of an inch, above, in thickness. The "angle-irons," or frames, which were double—the cross section resembling two L's in converse positions, as ⅂L screwed close together,—were, in measurement, 7 inches by 3, presenting one of the narrower flat sides for receiving the outer shell, and the other for the attachment of the inner covering, or ceiling

plank. Their distance apart was about 15 inches. The position of the ship's keel, as she rested on the blocks, intersected the magnetic meridian at an angle of 30°, the head being southerly; and the range of the blocks, in the direction N. 30° E. inclined towards the river, at an angle of 2° 15′ from the horizontal.

Though this ship was by no means completed, yet it was so far advanced as to afford all that was requisite for a conclusive experiment on the general characteristics of the developed magnetisms.

Before I approached the ship—the first I had ever visited whilst on the slip—I mentioned to my guide, Mr. Elder, jun., of the Vulcan Works —the leading phenomena, as regarded the external attractions, which I expected to find. The phenomena most confidently anticipated, were these:—

1. That I should find the whole of the *lower* part of the ship, at and about the keel and bilge, from stem to stern, powerfully attractive of the *south* pole of the compass.

2. That the *upper* part of the hull would present a contrary magnetism, and, consequently, attract the *north* pole of the compass.

And, finally, that I might probably find an *equatorial line*, approaching the midway betwixt the keel and the gunwale, in a neutral condition

as to magnetism, and where the compass would exhibit no influence whatever from the proximity of the ship.

It was very interesting to find, on making the trial, every anticipation thoroughly realized; but far exceeding in *intensity* of magnetic action, the effects I expected. The deviation of the keel, deflected only 30° from the magnetic meridian, was favourable for a satisfactory influence from the ship's attractions. For on approaching the keel or bilge with the compass, anywhere on the broadside, the needle—provided the attractive force of the ship's iron became absolutely dominant,—would have to deviate into a position forming a large and very conspicuous angle with its meridional direction. And this, in every part from stem to stern, on one side, and from stern to stem on the other side, proved to be the fact. Within about a yard of the *stem*, on the *starboard side*, the *south* pole of the needle pointed to the ship and adjusted itself in a position very nearly at right angles with the horizontal line of the iron-plates. Carried onward towards the stern, and presented anew at every fathom or two of distance, as I advanced, the needle of the compass was attracted in the same way, and, I imagine, with increased energy and force. As the stern was approached, the south pole began to incline a little, southward, towards the centre

of the ship, as it had done northward, at the commencement of the experiment. The compass being placed on the keel, near the stern (where the structure was not completed) the needle became parallel to the keel with its proper pole towards the south. Turning round the stern to the *port side*, the south pole of the needle deviated towards the ship, and regularly stood nearly at right angles to the direction of the line of the keel, as I advanced along that side towards the stem, where the circuit of trials commenced.

On rounding the bow, the south pole of the needle inclined towards the north; and opposite the stem, in the line of the keel, it stood at a deflection of 150° from its natural position, and in exact parallelism with the keel.—This terminated the series of trials of the ship's attractions on the level of the blocks.

Ascending to the stage erected near the upper works of the ship, and proceeding along it from stem to stern, on both sides, the attractions were uniformly exhibited in a deviating action, as they had been below; but with the poles of the needle reversed—the ship here attracting the *north pole* of the compass, and, at the distance of several feet, causing it to point directly towards the plates forming the substitute for the planking, or shell, of the ship.

The force of the attraction, however, far exceeded (as above intimated) what, without due consideration indeed, I had expected to find it. So energetic was the magnetic influence of this great mass of iron, especially below and about the main breadth and from thence aft towards the stern, as to attract the needle of the compass into a position very nearly at right angles with the horizontal line of the iron plates at the same level, at the distance of six or eight feet, or upward, from the bilge. About the middle of the hull, I crept beneath the bilge to the keel and found, as anticipated, the same direction of attractive force all the way out to the bilge, and extending, as just intimated, with little diminution of the deviating action to the distance of two or three yards beyond.

The search after a *neutral position*, at a medium elevation, proved very fortunate. A ladder of about 15 feet long happened to be standing near midway betwixt stem and stern, and leaning against a cross plank about a yard from the ship at the top. Ascending this ladder to within three or four steps of the top, I held the compass at the distance of a few inches only from the ship's side, and here found the *south* pole *feebly* attracted—indicating that the position was a little too low. Going a step higher, I found the needle now attracted by its *north* pole,

—indicating that I was a little too high. Lowering its place to an intermediate level, and holding the compass within a hand-breadth of the adjoining plate, no sensible action was found to be exerted by that immense mass of iron — the compass-needle adjusting itself correctly in the direction of the magnetic meridian of the earth!

Nothing, therefore, could be more conclusive than this verification of the leading principles asserted,—viz. that the whole mass of this iron vessel had received magnetism, not as derived from the rolling or other process of manufacture of the materials used, but simply and wholly from the earth's induction, augmented in power, and controlled into *direction* by the hammering of the rivets, and other mechanical violence impressed on the structure, in the progress of the building.

Whilst remaining in the building-yard, I tried the magnetic condition of the *interior of the ship*, in various places and at various elevations. The results, depending, as they necessarily must do, so constantly on the superior influence of the nearest and largest masses of iron, are not worth any particular description. It will suffice to say that, in most cases, the peculiarities of direction taken by the compass-needle admitted of easy explanation. The most peculiar and curious effect observed was when I hit upon positions, as

several times happened, where the government of the needle by the earth's directive force, was so nearly neutralized by the *reverse* government of the ship's interior iron,—that it exhibited scarcely any directive energy; the energy, as to the general resultant of the magnetic influences, being so feeble, that when the needle was made accidentally to deviate, it would sometimes go round and round, for a number of revolutions in succession, and then widely swing, with such sluggish tendency to return, as if solicited to a final adjustment by no decided polarity.

After my views, on the principles regulating the magnetic distribution in iron-built ships, had become more matured, I regretted that the magnetic force of the ship, at different positions in her length, had not been determined; and that I had not tried whether the neutral plane, as observed near the middle of the length, did not, in accordance with theory, and analogous to fig. 14, at page 269, rise high near the stern and become much depressed at the stem.

CHAPTER IV.

EXPERIMENTAL RESEARCHES ON THE OPERATION OF PRINCIPLES EFFECTING CHANGES IN THE DISTRIBUTION OF THE MAGNETISMS IN IRON-BUILT SHIPS.

SECT. I.—*General Considerations and Theoretical Views.*

THE principles on which the magnetisms in iron-built ships are developed, arranged, and distributed,—are the principles which must guide us in our consideration of the changes to which the original magnetic development is liable. As a general fact, terrestrial induction, as we have seen, is the sole and essential *power* from whence the magnetic condition is derived; and the *direction* of this terrestrial action is the principal and most essential influence in the magnetical arrangement and distribution. Percussion and other mechanical violence avail only in overcoming, what we have called, the molecular rigidity of the iron, which acts resistingly against the full operation of the inductive force of the earth. The same rigidity in the metal which resists, under the condition of quiescence, the full development of magnetism from terrestrial

action, serves to *retain* a high measure of the extra development derived instrumentally from mechanical violence, so long as the condition of quiescence is preserved. For this *retentive* quality of the molecular rigidity will, on the principles so largely illustrated in chap. III., part III., of the present volume, continue to be influential, notwithstanding various and great changes (quiescently made) in the position of the iron body with reference to that special position in which its high magnetic condition was originally developed.

Changes, however, in the relative position of the axis of terrestrial induction and the axis of magnetic distribution in the iron body—the hull of an iron-built ship, for example,—must *tend* to control the ship's now incongruous magnetic distribution, and to bring it into conformity with that of the originating power. Thus the magnetic distribution of the iron ship fig. 14, built with its head towards the south, must, on the swinging of the ship after launching, receive from terrestrial induction in the several other new positions of the keel we have figured, an influence *tending to change the original distribution* into the several forms, successively, of figs. 15, 16, and 17, belonging to ships constructed in these respective positions. The tenaciousness of the magnetism, however, is such, as so intensely

developed in the progress of construction, and as peculiarly supported, probably, by an augmentation of the power of retention in the molecular rigidity,—that there is but a small comparative yielding to the mere spontaneous influence of terrestrial induction, though acting in a new direction.

But the operation of mechanical violence, whilst the ship's magnetisms are thus subjected to influences tending to a new distribution, must, as all our investigations in chapters III. and IV. serve to demonstrate, give an additional efficacy to the controlling tendency of the earth's magnetic forces. Hence we feel authorized in affirming that mechanical violence, operating under the assumed alteration of circumstances produced by a change in the ship's position, must *alter*, in measure and proportion corresponding with the measure and extent of such violence, the distribution of the ship's magnetisms, (in all the *malleable iron*,) and the action of the *retentive* quality on the ship's compasses. And as the change in the place of a sea-going iron-ship may possibly be such as actually to *invert* the axis of terrestrial induction, with respect to its direction at the place where the ship was built,—we feel still further bold in maintaining that, if a measure of mechanical violence equivalent to that employed in the building were, under these new circum-

stances of position, impressed on the ship's fabric, it would not only change the whole system of magnetic distribution, but invert its axial polarity in conformity with that of the existing terrestrial action.

For as, on mechanical principles, the force sufficient to produce a given flexure on a beam of timber or rod of iron in a particular direction, should ordinarily suffice, if applied in the opposite way, not only to remove the original bend but to reverse it,—so we might fairly assume, what our foregoing investigations indeed have amply proved, that the magnetic condition, developed and partially fixed in any particular direction in a body of iron, may be both subdued and inverted by the like developing power when applied in the opposite direction.

Whilst *changes*, therefore, in the magnetisms of iron-built ships, subjected to due mechanical violence, must, under changes in their magnetical position, necessarily take place,—whether as to changes in the direction of the ship's head in the same magnetic region, or as to changes in the earth's inductive force and direction of its action within different magnetic latitudes,— the *quantity of change*, it is obvious, must depend on the relative bearing of the mechanical action on the sustaining rigidity of the iron.

Though an iron-ship can never again be sub-

jected to the same quantity of percussive action of the *species* employed in her construction, as that by which her original magnetic condition was developed and distributed; yet a very powerful and influential measure of percussive action, tending to change the magnetic distribution, may, and often is, impressed subsequently upon the general structure. In the case of iron-built *steam-ships*, this is specially the case, where, —in the fixing of the engines, and in the adaptation of the great surface of inside iron-plate sheathing designed for protection against fire, percussion, with the bending of sheet-iron, is carried on in such largeness of quantity,—the fresh mechanical violence, we believe, must have a powerful influence in aiding the terrestrial action in its tendencies to *alter* the general magnetisms of the ship. In the repairing of iron-built ships, again, or in the attachment of materials or apparatus to the hull where heavy hammering is required,—a like changing influence, having relation to the measure of mechanical violence, must reasonably be expected to be brought into operation. And besides these *incidental* occasions for a large and heavy measure of percussion on ships of this build, we have, in respect to steamers, the prevalent or almost perpetual action of the engines keeping the entire fabric, when under a high speed, in an unceasing

state of vibration and tremor,—a species of mechanical action, as our illustrative experiments have amply shown, possessing a very powerful influence in bringing the magnetic condition of bars or plates of iron into conformity, proximately, with the direction of terrestrial induction.

But there is yet another description of mechanical influence—probably more powerful in effective operation than those yet alluded to, to which every sea-going ship is necessarily subjected, which is the *straining* and *bending* action of heavy seas. The manner in which the fabric of an ordinary ship is liable to bend, twist, and strain, even under the simple operation of a heeling position, and much more when labouring in heavy sea, is indicated by such striking effects as to constrain the observation of every intelligent seaman. He finds doors, for instance, in the cabins and compartments below, which, if fitting nicely when the ship is in dock or harbour, not unfrequently sticking fast, or, perhaps, becoming so loose as to be liable to fly open, when the ship is "lying down," under a pressure of canvas, or heavily pitching against a head-sea.

That the effect of an influence of this kind is very decided, and must often amount to an actual change of figure of the sea-tossed fabric, may be safely inferred from the actual change in the form of the keel and sheer-lines, which, how-

ever varying in degree, or however inappreciable where iron is employed in the construction, invariably takes place on the launching of a ship. For the frame previously and equably supported from end to end on a range of well-grounded blocks, receives a new system of support for its length after being launched,—a system of support no longer equable in its bearings, nor proportional to the weight to be locally supported above, but depending on the quantity of displacement of water below. Hence, whilst the great body of the ship is fairly water-borne, the head and stern, with their weighty overhangings and appendages, depend less on the water than on the strength and firmness of their attachment to the general fabric and thus gravitate with so much force, as to cause that depression at the ends *tending* to produce the deformity called "hogging." In timber-built ships, weak in the frame or ill fastened, this flexure is at once permanent and considerable, besides being liable to increase with age and service. And although in iron-built ships it may generally be very small and extending little, perhaps, beyond the limits of elasticity of the materials; yet flexure must take place at launching, and changes in the flexure must necessarily occur whenever the ship is subjected to the unequal support of traversing waves. Thus

suppose a ship *crossing* the swell, where the extent from one wave crest to another might be correspondent with her length. Were the ship of a thousand to fifteen hundred tons burden, the waves of a width from crest to crest, equal to her length, might, if large, be from eight to ten feet in height, from the passing of which the series of straining and bending operations must be strong and perpetually changing. Thus, at one moment, with the body of the ship in the trough of the sea,—the extremities being then deeply plunged below their ordinary floating depth and the main-breadth raised somewhat above it,—the whole structure might be borne as equably as when the keel rested on the blocks; but in a few moments afterwards (probably in three or four seconds) with the wave-crest advanced to the midships—the middle of the hull being now *over* sustained, and the head and stern deprived of one-third, possibly, of their ordinary support, the general fabric would be strained by the heavy preponderance of the extremities, and that to an extent perhaps exceeding the effect of the original transition from the blocks to the water. The effect of all this might be equivalent to a force of, say, a tenth part of the ship's weight, (or incidentally, in a heavy sea, it might amount to some hundreds of tons) first lifting up the middle part of the hull and then raising the ends,

with a perpetual series of bending influences alternating in their action on the elasticity of the vessel, at intervals of only three or four seconds of time! To an extent often powerfully impressive on the feelings, these alternating movements derived from the diverse operations from mechanical violence, are forced on the attention of the most careless voyager. He feels the whole fabric of the ship thrown into violent vibrations, the effect of rapid changes in the elastic flexure, whenever she gives a heavy plunge, or reels, under the concussion, when struck by a sea.

Now these circumstances of mechanical violence, so powerful in their action as to be felt from stem to stern, and leaving no part of the vessel inert or unimpressed, may well be supposed sufficient, as I doubt not they actually are, to relieve the constraint of the ship's magnetisms from no small part of the molecular rigidness of the iron, and to yield a change in the original magnetic distribution into some measure of conformity with the newly disposing influences of terrestrial induction.

How far these changes, under the more influential forms of mechanical violence, may be thorough and complete, or to what extent they may act on the compass deviations, or be discernable by ordinary observations,—it would be presumptuous and vain to attempt to predict.

For *the tendency to change*, and for *the presumption of considerable and important changes*, we mainly contend;—the quantity of approximation in the ship's magnetisms, to the earth's inductive action, under any of the conditions referred to, being a question which observation and experiment, on the actual cases, can alone determine.

SECT. II.—*Application of Principles, theoretically assumed to pertain to changes in the general Magnetic Distribution of Iron-built Ships, to various systems of illustrative Experiments.*

THE deductions from recent researches given in the preceding section, corresponding with the indications of all our former experiments on the same subject, tend forcibly to show the inadequacy of any of the prevailing practices—whether by correcting magnets, or observations on the ship's deviating action—for rendering the mariner's compass a good or safe guide to the navigation of iron-built ships. For the principles referred to, being, when solicited by mechanical violence, energetic and operative in their nature, must render, it seems obvious, not only correcting-magnets fallacious, but any table of compass-errors, derived from observations made under circumstances of quiescence, defective. Hence the deviations of a standard-compass, as deter-

mined by the ordinary process of "swinging the ship," cannot, I apprehend, be safe for general application, since these deviations must be liable to be changed by the alteration of any of the circumstances essentially affecting the stability of the general distribution of the ship's magnetisms.

Under the firm conviction of the soundness of these views, I made a note—whilst contemplating the experiments hereafter described, but before the commencement of any one of the various series,—in respect to the differences to be expected in a table of deviations, under different changes of the circumstances liable to affect the results, of the following tenor:—

1. That, taking the ordinary method of observing the deviations as the general standard of comparison, a different series of deviations might be expected, if vibration or percussion, on the general body of the ship, were employed, *during the process* of swinging and observation.

2. That a different series, more in conformity with the earth's magnetisms, should be found, if the ship were swung immediately after heavy pitching, rolling, and straining at sea.

3. That a different series should be obtained, in the same vessel, when returning from a high magnetic latitude to a lower, from that obtained when coming from a low to higher,—in the

former case the technically called "permanent magnetism," should be in excess of the quantity ordinarily due to the place of experiment, and, in the latter case, in deficiency.

And, finally, that some observable diversity in the series might be expected, on the ordinary mode of ascertaining the compass errors, even on the mere change of the circuit made in swinging, such as from north, east about, to north, west about.

In investigating, experimentally, the operation of the principles engaged in producing changes in the general magnetic distribution in iron-built ships—under the contemplation of which the above propositions were predicated — the special proposition mentioned in the foregoing chapter, was assumed as the general basis of the designed system of researches. In may thus be substantially stated:—"That the combined influence of the various masses of iron distributed through all parts of a ship, seems to act on the compass as if concentrated (as to either polarity) into a kind of magnetic focus of attraction."

This principle, now generally received as true —that is, for any particular case, or magnetical condition of an iron-built ship—involves the obvious consequence, that all the magnetisms in a ship, for any such special condition, may be re-

presented by a single straight-bar magnet, placed in parallelism with the general axis of the ship's magnetic forces and with due adjustment to the distance and position of the standard-compass. As the axial direction, however, of such magnet, would in almost every case be in a position of obliquity to a horizontal plane,—the same, it is obvious, might be resolved into two rectangular forces, such as those of a horizontally and a vertically placed magnet. And two magnets, thus circumstanced, it appeared to me, might easily be made to represent, and that fairly, all the changes which take place, *quiescently*, in a ship's magnetism, whether by alterations in the direction of the ship's head, or by alterations in magnetic latitude. But as the quality of magnetism which is *changeable*, whether under mechanical violence or simple terrestrial induction, could not be thus represented,—the analogy, I conceived, would become at once satisfactory and complete, by substituting, with a view to illustrative experiment, *bars of malleable iron* for permanent magnets.

The general principle of operation, grounded on these considerations, was to determine the actual effects of two iron bars, or of a single bar revolving, successively, in different planes, whilst being swung round a fixed compass. The bar, when swung in a horizontal plane, would thus

represent, at least illustratively, the changes of the *horizontal* part of the magnetic forces in swinging a ship; and the same bar, placed upright, and again swung round the compass, would represent the influence exerted by the *perpendicular* part of these forces in the various parts of the circuit. The bar, again, being made to traverse *a vertical plane in the magnetic meridian*, would represent the changes of the vertical part of the magnetisms, under all the variations in magnetic latitude passed through by a ship crossing the equator and advancing into the southern hemisphere. And whilst these several series of experiments with neutral bars, together with corresponding series made with bars strongly magnetized by preliminary percussion, might represent the circumstance of *all quiescently* made *changes* in a ship's position; the subjection of the bar to repeated percussion or vibration, during the *progress of its circuit* on the several plans of procedure, might very well illustrate the principles by which changes in the *more* fixed part of a ship's magnetism are regulated; the changes, for instance, produced by the ship being vibrated in its fabric by the working of steam-engines, or strained by the action and violence of the sea, during transitions from one course to another, and from one region to another magnetic latitude.

SECT. III.—*On the Deviations produced by a Bar of malleable Iron, in different magnetic States, when swung round an independently fixed Compass in a* HORIZONTAL PLANE.

THE apparatus employed in the experiments now first to be described consisted, mainly, of two bars of cylindrical iron, a delicately acting compass, and a revolving deviation-plane.

1. The *bars* were similar in form and size, being of three-quarter-inch round iron, and three feet in length. They differed only in degree of hardness and finish,—one, marked U, being polished on the surface, but in the state, pretty nearly, as to *hardness*, in which it came from the rollers. The other, marked A, of rough surface, had been *annealed*, or softened, by being heated throughout to redness and slowly cooled. The ends of both were hemispherical and polished.

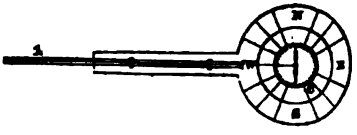
2. The *compass* was one of Kater's,—the same which had been employed in most of my magnetical investigations—with a needle of 4·9 inches in length. Though graduated only to half degrees, much habit in observation and subdivision enabled me easily to discriminate differences of two or three minutes.

3. The *revolving deviation-plane*.—Out of a circular piece of deal board, 15 inches in dia-

meter, a central circle was cut in the lathe of six inches diameter; and to one edge of the exterior circle an arm, two feet in length and four inches in width, was securely fixed in the same general plane. Straight lines, radiating from the centre of the circular pieces, were drawn across the surface of both to the extreme edge, including angles of $22^{\circ}\,30'$, equivalent to two points of the compass, the line representing the magnetic meridian extending along the middle of the projecting arm. The radii of the central disc were marked in accordance with their proper rhombs. On the middle line of the arm, two brass rings were screwed down: they were of such diameter within, as to receive the iron bar freely and support it steadily in its place, whilst observations were being made,—a brass stop being fixed in the middle line, proximate to the centre, for the accurate adjustment of the distance betwixt the nearer end of the bar and the compass.

This simple apparatus, when in use, acted with singular neatness and satisfactoriness. It was thus arranged:

Fig. 18.



On the middle of the surface of a heavy and firm table of deal, constructed without the employment of any iron therein, the central disc, c, was securely screwed, with its cardinal points

nuare sides of the table. Upon
placed the compass, guided
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compass-needle pointed
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idences.

djustments being satisfactorily effected,
nnular portion of the board, N. E. S. W.,
as put in its place on the table so as to receive the fixed disc within its interior opening, and to be steadily kept and guided thereby whilst being made to revolve around the disc as a centre. One of the iron bars, I, being previously and accurately neutralized as to magnetism, was then carefully slid into the guiding rings whilst the arm was placed in the line of east or west from the centre of the compass, and limited by the stop, to the exact distance, viz. eight inches, designed for the experiment. The compass reading being found to be still unchanged from the zero, the neutrality of the bar and the correctness of the adjustments, were shown to be complete.

Under these arrangements, varied only by the magnetizing, or demagnetizing, of the bar by percussion as the objects contemplated required, the first system of experiments—compendiously indicated at the head of this section—were made. The principal results, derived from many hundreds of observations, and some of them oft repeated, I have condensed and cast into a tabular form; which, for facilitating comparison, and for convenience in reference, are here exhibited at the commencement of our description and analytical remarks.

TABLE I.—Comparative Deviations produced by a Cylindrical Iron Bar (not annealed) of three feet in length, and three-quarters of an inch in thickness, whilst swung round a fixed Compass, in *a horizontal plane*, —the nearest end of the Bar being eight inches distant from the centre of the Needle and on the same level. The different Series of Experiments commenced generally with the remote end of the Bar pointing to the North.

Compass Direction of Iron Bar.	Mean Deviations by *Neutral* Bar.	Bar magnetized to 10° Deviation at the *commencement* only		Bar magnetized to 10° at commencement, and struck six slight blows at each station.			
				N. Pole next the centre.		S. Pole next the centre.	
		N. Pole next the centre.	S. Pole next the centre.	Before Hammering.	After Hammering.	Before Hammering.	After Hammering.
i.	ii.	iii.	iv.	v.	vi.	vii.	viii.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′
North	0·0 E.	0·0 W.	0·0 E.	0·0 W.	0·0 W.	0·0 E	0·0 E.
N.N.E.	0·58	4·26	4.17	4·15	0·36	4·43	4·22
N.E.	1·10	7·15	8·30	1·20	1·15	7·40	7·19
E.N.E.	0·37	8·47	10·0	2·18	2·22	8·23	7·40
E.	0·19W.	9·42	10 6	3 20	3·40	7·28	6·42
E.S.E.	1·0	9·42	8·52	4·19	4·52	5 43	4·44
S.E.	1·24	8·10	7·10	4·23	4·54	3·30	2·52
S.S.E.	1·6	4·20	4·10	2·56	3·4	1·30	1·10
South	0·0	0·0	0·0	0·0	0·0	0·0	0·0
S.S.W.	1·8 E.	5·8 E.	4·0 W.	3 20 E.	3·25 E	1·8 W.	0·55W.
S.W.	1 35	8·15	6.50	5 38	5·38	2·4	2·8
W.S.W.	1·4	9·48	8·34	5·48	5·40	3·11	3 40
W.	0·3 W.	9 46	9 20	4·56	4·25	4·32	5·12
W.N.W.	0·28	8·58	9·13	3·18	2·33	5·40	6·16
N.W.	0·57	6·50	7·44	1·30	1·0	5·31	6·2
N.N.W.	0·52	4·5	4·15	0·25	0 8	3·25	3·36
North	0·0	0 0	0·0	0·0	0·0	0·0	0·0
Residual Deviation West from Compass		9·47 E.	9·32W.	—	2·23 E.	—	6·55 W.

Note.—Columns v. to viii. exhibit the means of two sets of experiments: viz. the results of the north pole of the bar proximate to the centre, *commencing* at north, with the south pole proximate, commencing at south, being combined in columns v. and vi., and the converse relations in columns vii. and viii.

It may be proper, before remarking on these various effects, to request its being borne in mind, that the deviations registered are only really comparative in respect to the series (as read on a horizontal line in the table) on any particular rhomb, or on the line of any other rhomb equi-distant from the magnetic north or south. Thus whilst all the deviations of the N. E. rhomb, are strictly comparable, among themselves, throughout the seven columns of figures, they only admit of further comparison (except by calculation) with the other corresponding rhombs of N.W., S.W., and S.E. It should also be borne in mind, that the differences of the various rhombs, (except within the analogy of action of the bar on the compass needle, just referred to) yield no direct indication of the comparative degree of magnetic energy in the bar under these diversities of direction. This will be obvious when it is remembered that in the north and south direction, where the earth's inductive action was the greatest, we have *no* deviation, because of the coincidence of the direction of the bar with that of the meridional position of the needle of the compass.

But, with these limitations of comparison and direct intimation of magnetical force, it should, finally, be remembered, that the mode of action of the bar on the compass in these experiments,

as to the angular position assumed by the needle, is in close analogy, and therefore admirably adapted for our object, with the mode of action of a ship's magnetism on the needle of the compass employed in steering.*

We now proceed to the consideration of the table, and to the description of such particulars, as to the nature of the experiments and their results, as may seem best to apply to the principles sought to be elucidated.

1. The primary system of experiments was commenced by the trial of the deviations of the bar *when in a neutral state*, whilst being swung, in considerable diversity of circumstances, round the compass. Thus commencing at *north*, on the deviation plane—that is, with the end of the bar the most remote from the compass pointing towards the exact magnetic north—the bar, with its moveable circle, was swung *east* about, or in the direction of the sun's motion, and then, commencing at the same point, west about. It was next directed to the magnetic *south* at the commencement, and swung in the several series again east about, and then *west* about. In these four

* Though the position of the compass on shipboard differs from that in our experiments, by having a portion of magnetic force *abaft* as well as forward, whilst in ours the magnetism was wholly *forward*, yet there is nothing in this diversity calculated to interfere with the general analogy in illustration.

circuits (including several repetitions) the bar was carefully neutralized at the commencement of each circuit, and the deviations observed at each second rhomb.

The objects of enquiry herein were,—(1) the amounts and varieties of the deviations in the different positions, and (2) the differences of the deviations, if any, occasioned by the diversity in the commencement or direction of the circuit?

Column ii. of the table exhibits only the mean deviations of the neutral iron-bar, as derived from the entire series. But, as had been anticipated, the results of the several circuits were found to differ, though only in a comparatively small degree. Thus, when the circuit was commenced at *north*, a residual magnetism, producing a deviation of 0° 20′ W., (in the north pole of the needle,) was found on reaching the *west* point, where, in the outset, the bar had been neutral: and when the circuit was commenced at south, a residual force in the converse direction, or of 0° 14′ E., was indicated by the deviation. Hence it was obvious, as the deviations of each circuit indicated, that the several circuits must have also differed. By inference, then, our anticipated position, No. 4, would seem to be experimentally supported, viz. —

That the deviations observed on shipboard, may be expected in some small degree to differ, even

were the ship entirely free from augmented or retentive magnetism, by diversities in the point at which the series is commenced, or in the direction in which the ship is swung.

2. The next series of experiments, the results of which are given in columns iii. and iv., related to the deviations produced by the iron bar when, no longer in a neutral state but considerably magnetic, it was quietly swung round the compass.

The magnetic condition, in this case, was given by a vibratory hammering in a vertical position until, when tested on the revolving plane due west from the compass, or in the plane of the magnetic equator, it exhibited a deviating power of 10°. The plan of operation for producing the required effect with precision and facility, may, from its practical utility, be fitting for separate or special description after the manner adopted, in like cases, in part III.

[34. *Process for the adjustment of a specific degree of magnetic energy.*]—For producing, at first roughly and in excess, the required degree of magnetic power, a great number of smart blows with a small hammer, probably a hundred, or sometimes more, were required, which were struck whilst the bar was held, clear of the floor, in a vertical position, so as to vibrate freely in

the hand. The process was continued until a decided *excess* of deviating power was developed, as tested by putting the bar quietly into its place on the revolving deviation-plane, and adjusting the plane in the east or west line from the compass. Whilst the bar now lay steadily on its rests in the same parallelism with the magnetic equator, a slight blow or two was struck upon it with the handle of the hammer, the eye, meanwhile, watching the reaction on the needle. The blows or taps were continued, occasionally using, when the effect produced was too slow, the face of the hammer, until the deviation was reduced to the quantity required. The principle of this mode of reduction, by which such ready and precise results are attained, is found in the law before determined; viz. that vibration, or other mechanical action, *tends* to facilitate the influence of the earth's magnetism in producing, in malleable iron, a magnetic condition conformable to its own. As, therefore, with the bar in the plane of the magnetic equator, the tendency of the terrestrial action is to neutralize any existing magnetism,—the vibrating of the bar facilitates the change, and, on the plan employed, so gradually and manageably, that no difficulty was found in producing the required magnetic force to the nearest observable limit (that of about a couple of minutes) in the angle of deviation.

With the bar thus magnetized to the required energy, a considerable variety of experiments were made,—the adjustment, as to degree of energy, being carefully renewed at the commencement of each series. The main subject of enquiry was,—Whether a different series of deviations would not be found under each essential variation in the starting point of the circuit, in the direction in which the bar might be swung, and in the poles of the bar which might be placed proximate to the compass?

A comparison, by the eye only, of columns iii. and iv., will be sufficient to indicate the general fact of the existence of the expected differences. But attention to two or three particulars will show the accordance of the leading differences, arising from the different polarities being presented to the compass, with anticipations from theory. Thus, commencing at north, with the northern pole of the bar next the compass, we find the primary deviation of 10°, reduced to 9° 42′ at east; whilst with the southern pole of the bar, proximate, and making the same circuit, the deviation at east was increased beyond the original quantity, or to 10° 6′. For here, in the first instance, the bar lay from the commencement with its north pole *above* the magnetic plane, so that the earth's magnetism acted reducingly thereon; whilst, in the second instance,

the north pole was *below* the magnetic plane and thus derived a supporting, instead of a deteriorating, influence, from terrestrial magnetism. But the general action of the earth's magnetism throughout the circuit, was in both cases found to be deteriorating, producing a permanent diminution in the original force from 10° to 9° 47′ and 9° 32′.

Hence, again, we may infer, that in the case of an iron-built ship, brought into a highly magnetic state by the hammering and bending of the iron in the course of construction, or by other mechanical violence in vibrations or straining afterwards,—there should be a difference in the magnetic action of the horizontal iron on the compass, in however small a degree, according as the ship might be swung east or west about, or the swinging commenced at different points.

3. A final class, in this system of experiments, comprised the investigation of the effects of *vibrating the bar*, rendered magnetic as before at the commencement, *at each station* in its progress whilst being swung, and also under considerable variety of circumstances in the swinging.

The bar, in the outset of each circuit, was magnetised, as before, to a deviating power of 10° whilst lying in the line of the west point of the compass, with a distance of eight inches betwixt the proximate end of the bar and the

centre of the needle. At the first station from the meridian, and subsequently at each succeeding point on which the deviations were observed, the bar, whilst lying in its place, was struck six slight blows of the hammer, on different parts of its length; and the state of the bar, at each station, was noted both *before* the blows were given (col. v.) and *after* (col. vi.), in order to show, more distinctly, the effect of the percussion.

This series or class comprised experiments varied in very many ways,—such as with the north pole of the bar nearest the compass commencing at north, and then at south; and so, also, with the south pole of the bar in proximity. The differences, as to the results for the several rhombs, were also observed, both when the circuit was made in the direction of the sun's motion and conversely. Here the leading objects of enquiry were,—the differences of the deviations, in themselves, produced by the previously magnetized horizontal bar, whilst being subjected to percussion at each station of the circuit; the comparative deviations of the same direction of the bar under the diverse modes of performing the circuit; and the differences betwixt the deviations, when the bar was subjected to percussion in its circuit, and when, commencing with the same degree of magnetic power, it was *quietly* swung round?

The results, as a whole, I may again remark, united in establishing as scientific facts, the deductions from investigations of analogous principles which I had ventured, as predictions, previously to register.

A part only of the series, but a part sufficient for the establishment of the predicted facts of the leading enquiries, is exhibited in columns v. to viii. in the foregoing table.

Take, for instance, the first station from the meridian, with the *north* pole of the bar proximate to the compass, where we find the quiescent deviation of 4° 15′ W., reduced, by six slight blows of the hammer whilst the bar lay in its place, to 0° 36′ W. But, comparing this effect with what took place when the *south* pole of the bar was nearest the compass, we find, in the N. N. E. direction, the very slightest change, consisting only of a reduction from 4° 43′ to 4° 22′. So, again, in the N. E. direction, comparing columns vi. and viii., we find, a change produced by the second six blows, in the first case, to 1° 15′, being very nearly the condition of the neutral bar (col. ii.); whilst, in the second case, the reduction was so small as to leave a residual magnetism of 7° 19′.

Here the effect of terrestrial magnetism, in *reducing* the power under vibrations, where the direction was unfavourable, and in *sustaining* the

power where the position was accordant with the natural influence, was most satisfactorily and conclusively exhibited. With the *north* pole of the bar toward the centre (the remote end pointing northward), its position was above the plane of the magnetic equator—so disposing it to yield its magnetic energy to vibratory action,—but with the south pole proximate, the converse; so that the terrestrial action, tending to assimilate the magnetisms of the vibrated iron to its own spontaneous influences, almost neutralized the bar in the first position, which it so effectually sustained in the second.

These striking differences in the deviations of the same bar, magnetized to the same extent, and tested at the same points of the compass, have an obvious and important bearing on the *differences* likely to be elicited in the deviating action of an iron-built ship on her compasses, when determined on the quiescent swinging of the ship, and when observed in connexion with any violent percussion or vibration on the structure during the progress of the swinging. But the special application of these illustrative results—indicative of changes fully as important as any we had anticipated—are reserved for a future section. It is not to be assumed, indeed, that the *proportions* of change, in the actual case of a ship, could be correspondent with those we have

elicited in an iron bar *horizontally swung*, because the influence of the *upright force* in the iron, in our magnetic latitude, would, in all cases, be dominant; but that, as to the action of vibration on the horizontal force, there must, it is certain I conceive, be a strikingly influential and modifying effect.

Again, comparing the effects of percussion during the circuit of the bar, under the diverse polarities of columns vi. and viii., we find, consistently with theory, a converse result, after the passing of the E. point. For even at E. S. E., the northern polarity, being favourably acted on by terrestrial magnetism, becomes augmented so as now to exceed that of the southern polarity, on which the terrestrial influence has begun to act deterioratingly. At the S. E. point, the restoring influence on the one hand and the deteriorating on the other, had become such, that the end of the bar formerly so much reduced in energy acts with a power of 4° 54′ whilst the other, which had been so superior, is reduced to 2° 52′. In like manner, after passing the S. point, the northern polarity continues superior up to W. S. W., but after that, where terrestrial influence has begun to act as in the commencement of the series, the northern polarity again deteriorates whilst the southern increases, so that

at N. W. the former is found again to have fallen to 1° 0′ deviating power, whilst the latter has been raised to 6° 2′.

As to a final comparison, we may just notice the residual magnetism found in the bar after the completion of the two circuits, under a corresponding measure of percussion applied in each case. And here we find that, whilst the northern polarity (col. vi.) retained only a deviating power of 2° 23′, the other end had a residual power of 6° 55′.

These comparisons, if applied to the case of iron-built ships, will serve to elucidate still further the principles on which percussion, whilst being swung, must influence the horizontal action of the ship's magnetism on the compass, and to yield grounds for predicting, the *nature* (not the quantity) of the changes, in such horizontal action, which, apparently, must take place.

SECT. IV.—*On the Deviations produced by an Iron Bar, in different Magnetic States, when, being fixed in a* VERTICAL POSITION, *it was swung round the Compass in a* HORIZONTAL PLANE, *as before.*

IN the former system of experiments, the iron-bar had a horizontal position whilst being swung in a horizontal plane; and so was calculated to elucidate the nature and changes of the *hori-*

zontal part of the magnetic action in iron-built ships, whilst being swung round for the determination of what we may call the *rhombal deviations* of the standard compass on board. In this second case, however, the iron-bar was placed in a vertical position, in order to elucidate the nature and variations of the deviations under the influence of the *vertical* portion of the ship's magnetism. In all other respects, the experiments were conducted in a similar manner to those just described. An abstract of the mean results may suffice for the whole; and as neither the direction in which the bar was swung round, nor the point selected for the commencement of the circuit, could, in this case, have any varying or modifying influence,—the number of the points, reckoned from north or south towards the east or west, alone required to be registered in the table. It may also be noted, that as no effect could be produced by percussion at the several stations of observation, except a probable augmentation of magnetism to the embarrassment of the investigation,—the experiments were limited, primarily, to the deviating powers of the bar after being quite deprived of actual magnetism, and then to its powers, after being magnetized by percussion before commencing the circuit to the extent of 10° of horizontal deviation, whilst being swung round the compass in its new position.

TABLE II.—Comparative Deviations produced by Iron Bar, U, whilst, when being fixed in a *Vertical Position*, it was swung round the Compass in a horizontal Plane. The nearest or lower end of the Bar was eight or twelve inches distant from the centre of the Needle, and at the same level.

Compass Direction: Points.	Mean Deviation with the Bar neutral.	Bar magnetized to 10° at the commencement only.	
		Deviations at eight inches from Compass	Deviations at twelve inches from Compass.
i.	ii.	iii	iv.
	° ′	° ′	° ′
N.	0·0	0·0	0·0
ii.	4·10	14·52	6·0
iv.	6·46	19·44	9·20
vi.	7·44	20·30	10·20
E. or W.	7·58	20·0	10·40
vi.	7·38	17·47	9·30
iv.	6·25	13·50	7·20
ii.	4·3	7·15	4·0
S.	0·0	0·0	0·0
ii.	4·12	7·40	4·6
iv.	6·40	14·15	7·30
vi.	7·50	18·40	9·50
W. or E.	7·59	21·0	10·50
vi	7·34	21·30	10·30
iv.	6·33	20·0	9·13
ii.	4·8	15·0	5·40
S.	0·0	0·0	0·0

1. The deviations of column ii. in this table, would represent, obviously, the influence of the *upright portion* of the magnetic force in an iron-built ship, acting in the line or direction of the keel, as *simply induced, terrestrially, and dependent on position*. The circumstance of the proximity

of the lower end, or north pole, of the bar to the compass, instead of the upper, which is more usually dominant on shipboard, is of no consequence in respect to the *nature* of the magnetic action. As the angles of deviation have all their simple mathematical relation to the deviations at E. and W., the errors of observation, and the effects of obliquity in the needle in altering the relations of distance,—which in this case are unimportant,—admit of easy adjustment. But as no iron-built ship can, in a high magnetic latitude, be free from augmented or retentive magnetism, our observations are only available, illustratively, to show the proportion of augmentation, under that ordinary and moderate measure of percussion which yielded the results of the succeeding columns.

2. The deviations of column iii. may illustrate, proximately, the extent of augmentation in the power of the vertical portion of a ship's magnetism after a moderate measure of vibration or percussion. This is indicated roughly, by the increase of the maximum deviation from 7° 59′ (col. ii.) to 21° 30′ (col. iii.). A remarkable difference, it will be observed, is found betwixt the deviations (apparently analogous in their relations) of two points from the N. and of the same angular distance from the S.—the former being (col. iii.) 14° 52′ and the latter only 7° 15′.

A little consideration of the relations, mutually, of the bar and compass-needle in these two positions, will explain the apparent discrepancy. In the position of two points from the N., the north pole of the bar, in *repelling* the near end of the needle, was able to act at a large angle of incidence, and, therefore, with great effect; whilst in the like position in respect to the S., the south pole of the needle, now proximate, was brought more nearly into the direction of the bar's action, and, consequently, was operated on with a greatly diminished effect. But similar effects on a compass far aft, are, not unprevalently, found on shipboard, provided the distribution of the magnetic forces be tolerably equable, and the line of no-attraction coincident with the north and south directions of the ship's head, or the meridional position of the keel. One difference, indeed, may be noted, producing deviations, on certain points, in excess, where the nearest end of the five-inch needle being attracted, very considerably reduces the distance, and thereby augments the action, of the nearest and most effective pole. This source of error, though of no essential moment for our object, arises from the needle not being indefinitely short, and disappears, practically, in the deviations observed on ship-board, because of the small amount of the length of the needle, compared with the distance betwixt the needle and the general foci of the ship's polarities.

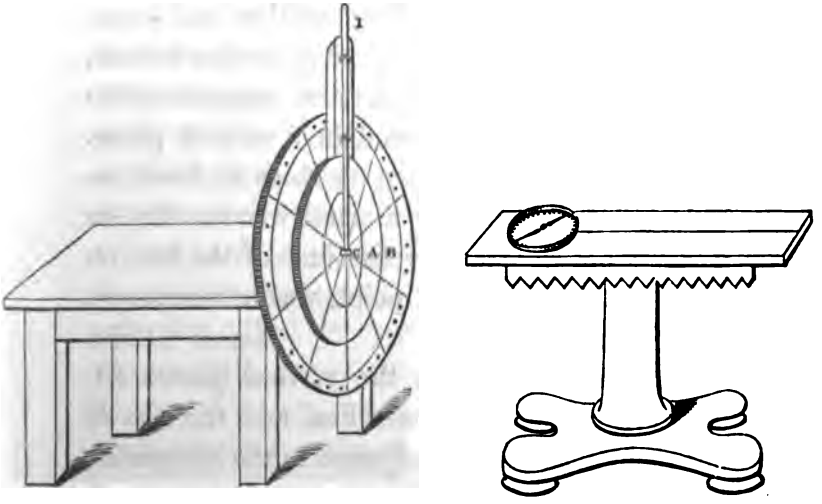
3. Comparing column iii. of this table of *vertical* action of the iron bar, with columns iii. and iv. of the table of *horizontal* influences, we find, on the east and west points of the former, a mean deviation of 20° 30′ and of the latter of 9° 44′, —indicating, in the relations of the tangents, a proportionate influence in the ratio of 374 to 172. The combined action of the two portions of the magnetic forces, represented by the sum of these tangents, or 546, being compared with the force of the neutral bar, in the two positions, which is represented by the tangent of the vertical force alone, column ii., or 140, (the horizontal part, on the east or west point, being nothing)— we get a notion of the proportions, illustratively, of the magnetism due to percussion and that simply derived from terrestrial induction.

And, these several particulars, not unfairly illustrate, I conceive, the nature of the magnetic action of an iron-built ship on her standard, or on her binnacle compass. The great predominance, too, of the magnetism not liable to change on the *quiet* swinging of the ship, may serve to illustrate and explain certain circumstances in Professor Airy's observations—as to the independent (or unchanging) magnetism greatly exceeding the induced; and as to the great intensity of the supposed permanent magnetism of the malleable iron of which the ship is composed.

SECT. V.—*On the Deviations produced by an Iron Bar, in different Magnetic States, whilst traversing in a* VERTICAL PLANE IN THE MAGNETIC MERIDIAN, *and acting on a Compass on the level of its nearer end, and preserving the same relative position by turning on its end as a pivot.*

THE object of this system of experiments was to illustrate the effects of *changes in a ship's magnetic latitude* on the spontaneously changing magnetisms; and likewise, on the retentive magnetism as influenced by vibration or percussion. The arrangements as represented in fig. 19, were as follow:—

FIG. 19.



To the end of the table employed in the former experiments, a large circular board B, placed in a vertical plane, was firmly secured, and, from the centre, a series of radiating lines were drawn across its surface, at angles of 10° apart. The *inclination* of the needle at the place of observation (Torquay) being assumed, proximately, at 70°, the line of 20° was made coincident with the horizontal end of the table, so that the graduation represented angles of dip, or, relatively to the local dip, angles of magnetic latitude.

On this vertical plane, the middle portion of the revolving *deviation-plane* A C, was screwed fast, with the centres of both coincident. The annular part, A, being then put in its place was secured from slipping off by another and somewhat larger central disc screwed to the former, which, however, allowed the arm supporting the bar to traverse freely round in a vertical plane. The bar I, was sustained in rings of brass, as before, and fastened by a small wooden slip or wedge; but the stop for the end of the bar, on which it turned as on a point, was now removed to the general centre.

Thus arranged, with the vertical planes adjusted in the magnetic meridian, and the line of 20° magnetical latitude adjusted to the horizontal, —the bar could be placed at any angle, and,

being fixed by a clamp, its magnetic condition promptly determined.

For the determination of such condition, the compass, on a fixed deviation-board, was placed on a separate table,—the level of the needle being made to correspond with that of the central point of the revolving-plane, and this central point, at the distance of twelve inches, being adjusted in the exact direction of the west point of the compass. Hence, in the absence of the bar, the reading of the compass was zero, and with the bar in its supports, the changing effects of its magnetism, with changes of position, or vibratory action, could be satisfactorily observed.

As the *annealed* bar A, whose magnetic action was greatly superior to that of the bar U, was employed in this system of experiments, the deviations were referred to a distance of twelve inches instead of eight; for at this greater distance, it was found, the deviations were very nearly equal to those resulting from the previous experiments.

A condensed abstract of this new system of experiments, is here, as formerly, exhibited in a tabular form.

TABLE III.—Comparative Deviations produced by a Cylindrical Iron Bar (annealed) of three feet in length and three-quarters of an inch in thickness, whilst traversing in a *Vertical Plane* in the Magnetic Meridian,—the proximate end of the Bar being twelve inches distant from the centre of the Compass and on the same level, and preserving its position, relatively with that of the Compass, by turning on its end as a pivot.

Magnetic Latitude of the Inclination of the Bar.	Bar Neutral.	Bar hammered at commencement only.	Bar magnetized at the commencement of each Series to a power of 7° 30′ Deviation, E. or W. horizontal, and hammered also at each Station.					
			Nine slight Blows at each Station.		About 50 smart Blows at each Station.		Reverse Series, commencing at foot, upward, with S. Polarity, 12 slight Blows.	
			Before Percussion.	After Percussion.	Before Percussion.	After Percussion.	Before Percussion.	After Percussion.
i.	ii.	iii.	iv.	v.	vi.	vii.	viii.	ix.
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
90N.	7·50E.	18·18 E.	18·15 E.	18·15 E.	19·47 E.	19·47 E	7·10 E.	8·15 E.
80	7·47	18·15	—	18.10	—	—	6·15	7·10
70	7·30	18·8	—	18·0	18·50	18·50	4·40	6·0
60	7·2	17·50	—	17·30	18·33	18·16	2·45	4·10
50	—	17·17	—	—	18·0	17·30	—	—
40	5·25	16·30	—	16·15	17·0	15·50	0·30W.	1·10E
30	—	15·35	—	—	15·2	13·0	—	—
20	3·0	14·27	14·15	13·20	12·4	10·10	5·10	2·45W.
10	—	13·0	—	—	9·0	6·32	—	—
0	0·15	11·45	10·30	8·16	5·20	2·38	9·50	7·46
10 S.	—	10·0	—	—	1·10E.	1·0 W.	—	—
20	2·4 W.	8·42	4·15	2·45	1·55W.	3·28	12·50	11·50
30	—	—	—	—	—	—	—	—
40	4·20	5·46	0·30E.	0·50W.	5·0	8·30	15·30	15·0
50	—	—	—	—	—	—	—	—
60	6·40	3·44	5·0 W.	7·15	9·58	13·30	16·15	16·15

1. The series of deviations, column ii., here exhibits the changes of magnetic energy in the bar, *when neutral*, whilst passing from a position in which the remote end of the bar pointed upward in the direction of the earth's magnetic axis, to a position (whilst traversing in a vertical plane past the zenith northward,) to 60° below the equatorial plane. The differences observable in the deviations of corresponding inclinations above and below the equatorial plane, are chiefly to be ascribed to the acquired magnetism derived from the commencing position, —a slight northern polarity being induced in the lower end of the bar, in the more vertical position, which, consistently with all general experience, does not entirely disappear in the plane of the magnetic equator.

This column may well illustrate the nature of the changes which take place in such part of a ship's magnetism (contemplating an equal distribution on both sides the keel), as depend simply on the spontaneous action of terrestrial induction. The deviations, in this application, represent the general effect of changes in magnetic latitude on the *maximum influence* of the *vertical* portion of the ship's magnetism,—that is, the influence as observed in its maximum action on the compass when on an *east* or *west* course only, (see table II. line E. or W.),—this being the special relative position of the iron bar and the needle.

Assuming, however, the two directions into which the general magnetic forces of the ship are resolvable to be equal or corresponding; then the same series of deviations, by merely changing the magnetic latitudes into their *complements*, will serve to illustrate, also, the changes in the *horizontally* acting magnetic influence; not, indeed, as operating *deviatingly* on the compass, but as expressing the varying quantity of the horizontal force, when at a maximum on a *north* or *south* course. This force, whilst at a maximum in energy on the line of the magnetic meridian, has, as we perceive by the series of deviations in col. ii. of table I., no action on the compass on that line (always assuming the magnetic distribution to be uniform on both sides of the ship) because of the direction of the action being coincident with that of the needle.

2. The alterations, produced by changes in magnetic latitude, in the portion of a ship's magnetism depending on simple terrestrial induction, as illustrated in the series of deviations, column ii.,—are well understood, and, in the various processes recently devised for the adjustment of the steering-compass, or for rendering its indications available for guidance in navigation, have had due consideration. So, also, have the changes in the *general magnetic distri-*

bution, as produced by like changes in magnetic latitude, received adequate attention; that is, so far as the assumption of a general measure of permanency in the retentive part of the magnetisms, might serve for guidance.

Of the changes in this general influence (or rather in the vertical part of the magnetic forces thereof) by changes simply of magnetic latitude without other disturbing cause, our deviations in column iii. seem to be fairly illustrative. For throughout the changes in the inclination of the iron bar, from the direction of the dipping-needle, or 90° of northern magnetic latitude, to 60° of southern, we find a continuance,—though in necessarily diminishing quantities because of the converse action of terrestrial induction,—of easterly deviations, indicative of an unchanged denomination of polarities. Hence, at the inclination representing the condition of zero in the position of the dipping-needle, where, on magnetism simply induced, the bar should have been neutral, we find the original powerful energy reduced only from a deviating action of 18° 18′ to that of 11° 45′.

To the extent of the changes thus illustrated by the experiments recorded in columns ii. and iii., therefore, the existing devices for correcting the compass errors are beautifully appropriate and fully adequate; but not so for the changes

to which the retentive magnetism is liable, when the substance of the iron-built ship comes to be acted upon by vibration, straining, or other mechanical violence.

3. In the succeeding columns, we have the experiments, illustrative of the principles regulating the magnetic changes in iron ships, when, on changing their magnetic latitude, they are subjected to mechanical violence.

The effects of percussion, applied at each change in magnetic latitude, are indicated by a comparison of columns iv. with v., and of vi. with vii. And the general result of successive applications of percussion, in the respective cases, where different quantities of mechanical violence were employed, will be represented to the eye by comparing column iii. with v. and vii. In such comparisons, whilst but slight differences are indicated during the progress from magnetic latitude 90° to 40°,—great changes appear in the succeeding series of latitudes, amounting to 9° 7′ at the magnetic equator (cols. iii. and vii.) and to 17° 14′ at south latitude 60°.

By a comparison, moreover, of the *rate of reduction* of the magnetic condition, as indicated in columns v. and vii., we observe the much more rapid tendency to neutralization by an increase in the number and intensity of the blows given

to the bar at the several angles of observation. Thus, whilst under the action of *nine slight blows* at each station, the north end of the bar did not cease to *repel* the north pole of the compass until a depression of near 35° of south magnetic latitude had been attained,—the same result, where *fifty smart blows* were given, was attained in the angle of about 7° of south magnetic latitude.

4. The converse of the experiments just described, is exhibited in columns viii. and ix. in the table. With the *southern* pole of the bar at the centre of the traversing motion, magnetized to the same extent as before, we have the effects of change in magnetic direction, by position and percussion—about a dozen slight blows being struck at each station of observation—from a position commencing with the angle of 60° S. magnetic latitude, up to the direction of the magnetic axis of the earth. The effects, we may perceive, were quite consistent with theory. Thus by changing the inclination of the bar, and hammering systematically in the upward progress of the extremity remote from the centre, we find the condition of no-attraction at about 34° of north magnetic latitude, and a really *neutral state* of the bar (as indicated by the equality of the deviations of columns ix. and ii.) in about 82° N.

All these results, we may observe, from beginning to end of the system of experiments, are perfectly consistent with theory, and with our predictions founded thereon. Their particular application to the object contemplated, will more fully appear in the following pages.

5. The combined result of simple terrestrial induction with the quality of retentive magnetism, and the relation of this result to that of magnetism terrestrially sustained, may deserve, from the important bearing of such combination on, and in relation to, the general subject before us, more distinctive elucidation. In order to this, I have made a selection of the more appropriate deviations of the last series, and have arranged their tangents again (with some additions) in a tabular form,—the tangent of 45° being considered as, on most former occasions, 1000.

TABLE IV.—Analysis of Table III., comprising the Tangents of Deviations produced by the Iron-Bar, for the elucidation of the combined effect of simple Terrestrial Induction and of Retentive Magnetism.

Magnetic Latitude.	Neutral Bar: col. ii.	Magnetic Bar traversing *downward*, col. iii.	Difference of cols. ii. and iii.	Magnetic Bar traversing *upward*.	Difference of cols. ii. and v.	Mean of cols. iv. and vi.	Hammered Bar, col. vii.	Hammering *ad infinitum*.
i.	ii.	iii.	iv.	v.	vi.	vii.	viii.	ix.
°								
80 N.	137	330	193	302	165	179	—	355
60	123	322	199	287	164	181	320	312
40	95	296	201	257	162	181	284	231
20	52	257	205	216	164	184	179	123
0	4	208	204	164	160	182	46	0
20 S.	36	153	189	123	159	174	61	123
40	76	101	177	85	161	169	149	231
60	117	66	183	66	183	183	240	312

The tangents in columns ii. and iii. are, as indicated at the head of the table, those of the deviations produced by the iron-bar in a *neutral* state, and *when magnetized at the outset* to a nearly maximum extent by percussion, whilst traversing, in each case, from a position representative of 80° N. magnetic latitude to that of 60° S. As col. ii. indicates the simple effect of terrestrial induction, col. iii. indicates the *sum* of that influence along with the retentive magnetism developed by percussion. Their *difference*, were the whole of the latter quality unalterably or equably retained, should have given an uniform

power expressive of the unvarying action of this special influence exerted by the molecular rigidity of the metal. But, by reason of the *sustaining* influence of the earth's action, operating very effectively in high magnetic latitudes, and becoming rapidly weakened in inclinations approaching the magnetic equator, the general series is rendered inequable. In order to correct and exterminate this sustaining influence on a bar traversing from 80° N. to 60° S., *downward*, I have added the tangents of another series of deviations (not included in table III.) with the bar, in its undisturbed magnetic condition, passing from 60° S. to 80° N., *upward*. This second series is also inequable, but, under a converse influence from the earth's sustaining power, the inequalities are cast in converse order. Hence, combining the results of the upward and the downward series, we obtain the *mean* force exerted by the retentive magnetism at the several angles of inclination, as shown in column vii., separately, which—omitting the inclination of 40° S. wherein I have reason to believe the angular position of the bar was somewhat inaccurate—is seen to possess a very satisfactory degree of uniformity,—an uniformity, indeed, such, that the greatest variation from the general mean of tangent 179, (with the one exception noted) amounts only to tangent 5, being but the thirty-sixth part of the general retentive force.

Had the *stations'-percussion*, col. vii. of table III., been carried to the extent of producing a fixed or unalterable condition of the bar at each angle of inclination examined, then would the differences of the tangents of columns ii. and vii. have yielded the quantity of magnetism *terrestrially sustained* in the several magnetic latitudes, —amounting at the latitude of 90° to tangent 360, and from thence reduced, in the ratio of the sines of the several angles, to nought at the position representative of the earth's magnetic equator. In this way, the force of *the magnetism terrestrially sustained* under violent percussion or other mechanical action, carried on *ad infinitum*, would be represented by the series of tangents given in col. ix. of table IV. The comparison of this series with that of col. viii.—exhibiting the tangents of the deviations (col. vii. of table III.) produced under stational percussion to the extent of about 50 smart blows with a small hammer—will serve to show, by the differences, the extent in which the original magnetism of the bar was still sustained throughout the series by the molecular rigidity of the metal, or in the form of retentive magnetism.

RESULTS.

As my investigations on the principles operating *alteratively* on the magnetic condition of iron-built ships have had scarcely any verification from the personal examination of actual cases,—the results now attempted to be deduced are necessarily wanting in that decisive element of proof by which, in all the preceding deductions, our conclusions have been supported, and, I hope I may add, demonstrated. At the same time, it may be submitted, that so correspondent was the material employed in our experiments with that of iron-built ships, so cognate the influences operating on both, and so decidedly identical the principles actuating the magnetic changes,—that we are justified, I conceive, on the strictest principles of inductive science, in both reasoning from the effects we have elicited, and applying the results, predicatorily, to the varying indications of the compass in vessels of the kind and quality under consideration.

1. That ships built of iron, in place of timber

and plank, obtain, necessarily, *an extremely high degree* of magnetic development from the elaborate system of percussive action, as well as from the bending of the plates and bars, during the progress of their construction.

The *process* of construction of iron-ships, it will be seen, must necessarily operate,—according to the principles elicited in our experiments on the development of magnetism in soft iron or steel by percussion and other mechanical action,—in producing the high magnetic effects enunciated in this proposition. For beyond the ordinary operation of percussion on each individual plate, it becomes subject to a most powerful action of the nature of our "compound process," (page 177),—a process, in the actual case, in which the mechanical action on every side of the plate, and the developing energies of all the surrounding plates, become united in the eliciting of the same polarities, and, manifestly, in the most energetic degree.

2. That the dominant magnetism thus developed is of the *retentive quality*,—a quality remaining whilst terrestrially sustained by consistency of position, and otherwise, also, in relations inaccordant with terrestrial influence, whilst the ship remains free from mechanical violence or other magnetically disturbing force.

This result, whilst plainly deducible from the foregoing researches, is verified, in substance, by the experimental determinations of Mr. Airy in respect to the iron steam-vessel, the Rainbow. Subsequent re-

searches, also, on the magnetism of iron-built ships, and its action on the compasses on board, go abundantly to confirm the same general proposition.

3. That in each iron ship there is a special individuality of the magnetic distribution, depending *essentially* on the position—characterised by the direction of the keel and head—whilst building, and *peculiarly* on the deviations from uniformity in the placing of occasional heavy masses of iron.

The principles described, with the considerations elucidated in chap. III., sect. I., can hardly fail, I think, to justify, if not to render inevitable, the conclusions here affirmed.

4. That, after being launched, percussion, vibration, or the straining of the general frame of iron-built ships, must *tend* to equalize the relations of the ship's magnetisms with those of the earth; and that the state of equalization, or approximation thereto, will be hastened and advanced, accordingly as the quantity or intensity of mechanical violence is increased, and accordingly as the ship's head is kept pretty steadily in the same direction.

The general tendency of all the experiments of this present chapter is to the support of this proposition, whilst the concluding section of it is well illustrated by the comparative results of columns v. and vii. of table III.

As to the general proposition, let a steam-ship, for example, be built in the position of fig. 14 (page 269) with the head *south*, and, on being launched, suppose her to be laid alongside of a quay running *east* and *west* to have her engines put in. Then all the strong percussive action, with the consequent effects in the production of vibration and flexure of the original structure, *must tend* to occasion a change in the general magnetic distribution into some measure of conformity with the lines of fig. 15, if the head be directed eastward, or of fig. 17, if westward. As to what the *quantity of change* thus produced may amount to, we have no adequate or appropriate data for determining; but as to the fact of *a change* in the magnetic distribution under the circumstances assumed, being inevitable, it is impossible, I think, with the results of the foregoing researches before us, reasonably to doubt.

5. That as the conformity in the ship's original or prevalent magnetic distribution to that of the earth's influence in new positions of the ship's head and new regions of magnetic latitude, can only be *proximate*,—the changes in the ship's magnetic condition must always fall short of, or lag behind, the amounts theoretically due to changes in magnetic latitude.

This proposition, which is plainly indicated by the results of the experiments given in table III., as already remarked on, will receive further evidence from a simple comparison of the equatorial deviations of columns v., vii., and ix., (the deviations as modified by a progressive percussive action during the

revolving course of the iron bar) with the *neutral condition* to which, according to the actual tendencies of terrestrial action, the bar should have arrived. Thus, under a slight measure of percussive action we find the magnetized bar reduced from the quiescent state of 11° 45′ (col. iii.) to 8° 16′ (col. v.); under a larger quantity of percussion, we find its action reduced to 2° 38′ (col. vii.); and, under a moderate quantity of percussion, with a reverse direction of change in the bar's angular position, we find the deviating action to have altered only to the reduced quantity of 7° 46′ (col. ix.). From each of these cases, however, our proposition derives distinct and characteristic evidence; evidence at once illustrative of the fact of a change of magnetic distribution *tending to accordance* with changes of magnetic latitude, but *always lagging behind.*

Our proposition is in perfect accordance with an important fact, which observation had determined, and which is taken account of in the practical methods for adapting the known compass-deviations to changes in the ship's magnetic latitudes. Thus, in the "Instructions for the Adjustment of a Ship's Deviations on a Change of Magnetic Latitude," by Archibald Smith, Esq., of Lincoln's Inn, the circumstance referred to is thus noticed:—"It is found that *time* is required to develop the change of the magnetic state of the ship consequent on a change of dip; and that a more correct result is obtained by taking the amount of the changing part of the deviation to be proportionate to the tangent of the dip in the geographical position in which the ship was a week or two before." This article in the practical instructions given to the navigator of iron-built ships, it will be observed, is at once elucidated and justified by our

researches; the true explanation, however, not being in the circumstance of *time*, but rather in the quantity and intensity of the mechanical violence, in connection with the favouring action of a magnetic position *beyond* that in which the ship was a week or two before.

6. That, as the ship's magnetic change, must lag behind the terrestrial changes, whilst passing from a higher to a lower, or from a lower to a higher magnetic latitude,—the closeness of the relations of the ship's magnetism with those belonging strictly to her geographical position, must be specially and more rapidly promoted by gales of wind and the action of heavy seas.

In the case of an iron-built ship, proceeding on a southerly course from a port or place in a northern latitude,—the effect of pitching and rolling, but more particularly of pitching, will be, not merely to facilitate changes in the ship's magnetism by the vibrating and straining of her frame, but by giving the effect of a more *advanced position* in magnetic latitude, whenever the keel becomes considerably inclined to the horizontal line. For instance:—let a ship be supposed to be traversing a heavy sea, in the manner of "scudding," whilst proceeding from a northern region towards the south, and that she has reached the magnetic latitude of 20° N. Suppose, then, whilst supported in a straining condition amidships on the crest of a following wave, her head to be alternately lifted and depressed to an extent of 10° from the horizontal; in such case, the vertical portion of her magnetic distribution would be acted on inci-

dentally, by the earth's magnetism, as if she had advanced southward to 10° of magnetic latitude. The effect of this, illustratviely, is indicated in col. vii. of table III., wherein a change from 20° to 10°, in the inclination of the iron bar, produced a change in its magnetic force when subjected to percussive action, represented by the change of deviations from 10° 10′ to 6° 32′,—the latter not being very remote from the true magnetic force due to the bar at the greater angle of inclination.

Hence we infer, that a measure of change in a ship's magnetic distribution, which if traversing a calm sea would require an advance through several degrees of magnetic latitude to effect, might be expected to be realised (as to the vertical portion of the ship's magnetisms) by the mere straining of the ship, on a southerly course, whilst thrown out of level to an angle, inclined to the horizontal, of a like number of degrees.

7. That the effect of changes in magnetic latitude on a ship's magnetic distribution—that is, on the vertical and, with us, the dominant part of her magnetisms—should vary greatly, in respect of progress and proportion in different regions, so as to be very rapid in low, and very slow in high, magnetic latitudes.

The *rapidity of the changes*, in equatorial regions, in the vertical part of a ship's magnetisms—the part which remains unaltered by change of course or direction of the ship's head—is strikingly indicated by the results of columns v., vii., and ix., of table III. From 20° N. to 20° S., representing a change of 40°

of magnetic latitude, there was an alteration in the deviating action of our bar, as shown in col. ix. of 9° 5′, and in col. vii. of 13° 38′. But passing, in a *high* magnetic latitude, the same interval, as, for instance, from 90° to 50° N., we find a change in the deviating action of the same bar, col. vii., though subjected to percussion equally as before, of only 2° 17′. Thus whilst a difference of 40° of magnetic latitude in equatorial regions indicated a change equal to about two-thirds of the maximum vertical force; the same alteration of latitude from the magnetic pole downward, indicated a reduction in deviating action of only a ninth!

The slowness of the changes in the magnetism of the bar whilst traversing the sections where the inclination of axis to the horizon is great, may serve to explain, I think, the apparent favourable operation of fixed permanent magnets, on Professor Airy's principle, for correcting the errors of the compass, within considerable ranges of high magnetic latitude. For, if our analogy be proportional, as well as otherwise complete, we should expect that the *retentive magnetism* and the *magnetism terrestrially sustained*, would (as to the *vertical*, and, *whilst so sustained, fixed part* of the ship's magnetisms,) only slightly change within the range, for instance, of most European ports, or other regions, under any meridian, in like magnetic latitudes. This fact, indeed, (for we hesitate not to assume the fact) taken in connection with the increase of the earth's directive action on the *horizontal* needle when going southward, on the one part, and the increased influence of the horizontal magnetic force, whilst the ship's head is kept steadily towards the south, on the other part, might, not improbably, reduce the differences of the compass errors, under

the ordinary operation of the mechanical violence inducing changes, to a limit so narrow as not to be easily detected.

8. That combining the changes in the *vertical* and *horizontal* portions of a ship's magnetisms, whilst passing through considerable intervals of magnetic latitude, we are led to anticipate a great difference, in the progress and extent of the actual alterations affecting the compass deviations, betwixt the case of a steam-propelled ship pursuing a regular and direct course, and a sailing ship whose track may happen to be very devious, and frequently changing.

Let us consider, for example, these two cases, in respect of vessels proceeding southward, from this country into a tropical region. We will suppose the two vessels of similar build and arrangement of their compasses, and with their chief magnetic force in the line of the keel, to proceed together, or in the same line of direction on a south-westerly course, steering for the Cape Verde islands, till reaching the parallel of 20° N. latitude. The wind we will further suppose then changes, so that, whilst the steamer pursues her original course without alteration, the sailing ship is thrown on a transverse course, on a wind. Up to this point, assuming a corresponding effect of mechanical action, we should expect the vertically acting magnetisms, as indicated by table III., columns v. and vii., to have greatly subsided. At the same time, the *horizontally* acting force, whilst pursuing a regular course south-westerly, must,

under the greatly diminished angle of the dip, have become much augmented; so as—reckoning the southern focus of the ship's attraction to be *forward* of the compass—to maintain a high degree of deviating action. But, whilst this quantity, regularly *sustained by terrestrial influence*, must continue little altered in the case of the steam-propelled ship, up to her arrival among the islands,—a very different result would probably be realized in the sailing-ship's devious progress. If labouring and plunging, for example, on an *east* or *west* course, the tendency (under the distribution of magnetisms assumed) must be to *neutralize* the horizontal force and so to diminish, probably in a very considerable proportion, the quantity of the deviation. If so, the deviations of the two ships, or, what is equivalent thereto, of the same ship under the like diversity of circumstances, might be expected to be greatly different, and the effect of such difference, or change, greatly embarrassing and dangerous.

Again, to take another case, as to the probable difference of deviations in an iron ship when entering the British Channel under the diverse circumstances of a previous northerly or a southerly course. It is obvious, from the results of table I., on the changes of the horizontal force, that, in a vessel descending from a higher latitude, to the parallel of 50°, and then hauling up, to the eastward, for entering the Channel,—her compass deviations must be different, we would venture to predicate *very different*, from the deviations of the same ship if ascending from a southern latitude on a northerly course, and then, at the same point, hauling up to the eastward. And should it so happen, as, in our figure 14, seems to be not impossible, that the plane of no-attraction

of the ship coming from the northward should rise above the plane of the compass, then must the magnetic action in these two cases *differ extremely*. For where the horizontal force, in its dominant influence, might present, in the one case, a polarity *attractive* of the north pole of the compass, it might exert, in the other case, a *repellent* action. The effect of this diversity of character in the dominant polarity appears, theoretically, to be such, that the compass would be acted on, deviatingly, by the *sum* of the horizontal and vertical magnetic forces of the ship, through the adjustments due to one course, and by their *difference* in the other.

9. That whatever may be the statical condition of a ship's magnetisms for *an upright position*, when proceeding steadily on any determinate course, a change must take place in her deviating action on the compass by the mere change into a *heeling* position.

The change here asserted, as resulting from a heeling position, is well known to take place, and is, theoretically, well indicated in Mr. Airy's paper on the iron-ship "Rainbow."

Independent of the effect on the magnetism of the retentive quality by the ship being heeled over to one side, the extent of which can hardly be guessed at,—a certain, precise, and inevitable change must take place in the adjustment, or direction of action, of the magnetism derived simply from terrestrial induction.

An inspection of our figures 15 and 17 (p. 269), will be sufficient to show the inevitable truth of this proposition. If, for instance, the ship with her head

lying east, were heeled over to port, the angle of the polar axis, represented at 20° from the perpendicular, might be increased to 30° or 40°; and, if she were heeled over to starboard, it might be reduced to 10° or, indeed, the polar axis might be brought into a position vertical to the keel. And as this quality of magnetism is changeable instantaneously on any change of position, the action thereof on the needle must vary, not only as the ship is gradually inclined to one side by the pressure of the wind, but with every alteration in the angle of heeling, as she is made to roll heavily in the trough of the sea.

10. That besides the causes hitherto elucidated as effective of changes in the magnetic condition of iron-built ships, the intensity or energy of the magnetic force in such ships must vary with the changes in the magnetic force of the earth.

There are two principles on which alterations in the force of terrestrial magnetism may act, changeably, on any previously existing quantity of a ship's magnetism. Thus, 1st, the development under *simple terrestrial induction* must necessarily be far greater in polar regions than in places nearer the magnetic equator. Even within the range of latitudes passed by a ship sailing from England to the West Indies, a reduction in the earth's magnetic force may take place to an extent of almost one-half. And, 2dly, the quantity of development in the ship's magnetism of the *retentive* quality, must also be liable to change with changes in the earth's magnetic force. In the event of the ship's *original* magnetisms having a *maximum* extent of development, as was the case,

very nearly, with the iron-bar in the experiments recorded in table III.,—then all reductions in the earth's magnetic force *must tend*, under mechanical violence, to reduce the general energy to the maximum measure of development which would have been elicited had the ship been built under such diminished force of terrestrial induction.

This fact receives the highest proof, except that of the actual observation of the special case in an iron-built ship, from our experiments with iron bars magnetized to a maximum by percussion in the line of the earth's magnetic axis, which were then found to be invariably reduced on applying further percussion in any other position. Thus, as seen in table III., the maximum power of the bar which, at 90° magnetic dip, was 19° 47′, col. vii., was reduced, in the position perpendicular to the horizon to 18° 50′, and at the dip of 30°,—representing a reduction of the magnetic force by inclination of one-half—the action of the bar on the compass fell to 13°; a degree of reduction (being corrected for the influence of change of position as shown in col. iii.) amounting to 4° 4′, but which, had the hammering been carried on to a maximum effect, would, no doubt, have been several degrees more.

11. That hence it appears, finally, that every change in the direction of a ship's head, or in the inclination of the keel when pitching, or in the inclination of the masts when heeling or rolling, or in the force of terrestrial magnetism, or in the direction of terrestrial action as varied with the magnetic latitude, or in the ordinary

differences of temperature in the ship's hull,—must necessarily operate towards the producing of change, (to some imaginable extent in each case,) either in the general distribution, or degree of energy, of the magnetisms of an iron-built ship.

These several influences, here given in summary, tending to produce changes in the magnetic condition of an iron-built ship, are plainly deducible from the researches described in the foregoing pages. The effect of changes and inequalities in the temperature of the hull of the ship, will be found to be more fully elucidated in the first section of the chapter following.

In respect to the operation of these several influences on the various *qualities of magnetism* in an iron-built ship described in the definitions suggested at page 129, it may be here noted, that the whole (with the exception possibly of that last named) are necessarily and instantaneously operative on the quality of magnetism derived from *simple terrestrial induction;* the whole tend, too, wherever there in an attendant disturbance by straining, vibration, or other species of mechanical violence, to affect the condition of the quality of *retentive magnetism*, and, except where such quality may happen to be *terrestrially sustained*, to alter the general magnetic condition so as to produce some characteristic change in its deviating action on the compass.

CHAPTER V.

ON CERTAIN *SPECIAL* INFLUENCES CALCULATED, NOT IMPROBABLY, TO AFFECT THE MAGNETIC DISTRIBUTION, ITS MEASURE OF FIXIDITY, OR ITS CHANGES IN IRON-BUILT SHIPS.

SECT. I.—*Experimental Enquiry concerning the Measure of Fixidity of the Magnetism actually developed in the Plate-Iron of a Ship during the progress of the building.*

WE have been led to conclude, and on grounds so satisfactory, it is believed, as to admit of scarcely a question, that no such quality as *permanent magnetism* can be elicited in the malleable iron of iron-built ships, either from the manufacture of the metal itself, or from the mechanical violence employed in its application to the general fabric of the ship. For all our experiments have gone to show, that whatever developments of the magnetic condition might be effected by the ordinary agency of mechanical action, must be liable to be changed, neutralized, or reversed by a repetition of similar or proportionate violence, if administered under circumstances

adapted, in accordance with the laws of terrestrial induction, for such alterations.

In one respect only, as far as I am aware, have our experiments fallen short, in strict analogy, of the accordance requisite for an absolute conclusion as to the conditions of mobility in the magnetism of iron ships. For whilst abundant experiments had been made on all the kinds and qualities of metal employed in the construction of iron ships, and on all the peculiarities of magnetic development which ordinary mechanical violence might elicit, no opportunity was afforded me of testing the nature of the magnetism,—as to its extent of development and general mobility, — in any portion of iron which had actually formed a part of an iron-built ship.

Desirous of making this investigation so as to complete the entire series of imaginable analogies by which the solidity of our conclusions might be affected,—I applied to my friend Mr. James Napier, of Glasgow, for the means of putting some specimen, which had previously formed a portion of the exterior covering of an iron ship, to the test of experiment.

With such a portion of plate-iron I was kindly and promptly provided. It was forwarded to me at Torquay at the very time when this portion of the present volume was in course of arrangement for the press. It was found to be nearly an

oblong square, 24 by 30 inches, measurement of surface, and three-eighths of an inch thick. According to Mr. Napier's description, which I give here in substance, the piece of plate was cut out of a vessel of 1100 tons. It was removed for the formation of one of the side windows, and appeared to have occupied a position about 23 to 27 feet (horizontal distance) from the stern-post, and about 24 feet (perpendicular distance) from the keel,—the top of it being 18 or 20 inches below the poop-gunwale. The vessel's head, whilst building, lay S. 12° E., and the keel had about half-an-inch to a foot of inclination on the blocks.

For the testing of the magnetic condition of this specimen of plate-iron, a strong kitchen table was adjusted with its sides in parallelism to the cardinal points of the compass. Upon the surface of this table, the plate was rested during the experiments, with a compass contiguous thereto; and when *particular accuracy* was required, the compass was placed on a separate tripod table. Thus any of the edges of the plate could be accurately made to range in the north and south, or east and west, magnetic lines, by the simple guidance of the position of the table, and the relative magnetic action of such edges determined by the compass deviations. The edge to be tested was always placed

in the line of the magnetic meridian, with the compass to the east of the *middle* of such edge, and at the distance of six inches. Under this adjustment, when the plate was laid flat on the table, the needle of the compass must necessarily lie in parallelism with the proximate edge of the plate, provided the plate was free from sensible magnetism; or when not magnetically neutral, the needle must be deflected, north pole eastward or westward, according as it might be influenced by northern or southern polarity in the near edge of the plate. The edge of the plate which had been *upward*, whilst it formed part of the ship's side from whence it was removed, was distinguished by the letter U, and the downward edge by the letter L. The end which had been *forward* in the ship was also distinguished by an *f*, and the *after* end by an *a*.

In the first series of experiments,—designed for ascertaining the condition of the plate, magnetically, as it came into my hands,—the observations of its deviating action were made with the plate held *upright* on the edge nearest to the compass, when the magnetism of position being combined with the retentive magnetism, afforded the means (taking the average deviations with opposite sides upward) of determining their relative proportions. But the retentive quality proved to be by no means energetic, being

scarcely a fourth-part as strong as that derived from simple terrestrial induction. And, to my surprise, it further proved, that the polarities neither corresponded with what theory would have indicated, as to their general direction, nor as to the denominations of the poles in the two sections of the plate. The fact was, that the equatorial line passed obliquely (almost diagonally) across the plate, and the edge U exhibited northern polarity instead of southern! It hence appeared, that either the upward edge had been erroneously marked, or else some accidental percussion or other mechanical violence had actually reversed the original polarities.

Another set of experiments on the effects of percussion, whilst the plate was held on edge, served to indicate that the latter supposition was most probably the correct one. For on striking the plate a few blows with the back of a small axe, the magnetism was found to be just as subject to control and change as in the experiments with the new iron-plate described in chapter II. Thus, on whatever edge the plate rested when it was struck with the axe, that edge obtained, after half-a-dozen blows or less, a dominant northern polarity. Whilst, therefore, with the edge originally possessing a northern polarity *downward*, a few blows greatly increased its deviating action; with the same edge *upward*, a

few similar blows sufficed, not merely to disperse the original polarity, but to reverse it. Hence, finding the magnetic condition of the plate so little energetic, at first, and so very mobile in its disposition, it was natural to assume, that since the cutting out of the plate its magnetism had been changed; and that the change which seemed to have taken place might probably have been produced by the plate being allowed to fall, or to strike a blow on the ground, whilst let out of hand, with one of its corners downward!

A final set of experiments was made on the same plate with the view of ascertaining, whether any particular disturbance in the equilibrium of the molecular magnetisms had been produced by the severe hammering it must have encountered whilst being attached to the frame of the ship?

For this series of experiments the compass (a more delicate one than that before used) was placed on a separate stand, whilst the plate was laid flat on the kitchen table, with the middle of each of its sides, in succession, adjusted in the north and south line, at the distance of six inches, westward, from the compass.

Two modes of testing the condition, as to equalization, of the molecular magnetisms of the plate were adopted:—1st, by determining (after the plate had been rendered non-magnetic) the

action of a single blow, struck as equably as possible, whilst the plate was on edge with the sides U and L, or *f* and *a*, alternately upward, and then testing the quantity of magnetism elicited when the plate was restored to its horizontal position. And thus tested, the powers of U and L, on one trial, were indicated by 10° and 11° deviation; of *f* and *a*, by 17° and 18°. On other trials, the differences proved equally inconsiderable, and not quite uniform in their relations: consequently, it could be fairly inferred, that there was very little, if any, molecular disturbance in the magnetisms of the plate. 2dly, the molecular condition was also tested by marking the effect of percussion when the plate was carefully adjusted into conformity or parallelism of position with that of the earth's magnetic equator. One edge of the plate, on trial in this position, was found to possess a deviating action of 5° E., which was neutralized, very nearly, by a single blow with the back of the axe whilst it remained in the same plane; and, after twenty more blows had been struck, the neutral condition still remained undisturbed. Hence it was again concluded, that there was no essential magnetic disturbance in the molecular equilibrium, otherwise the apparaent neutrality so readily produced by the first blow, would have been disturbed (on the principle elicited in

chapter VI., part III.) by the continuance of the percussive action.

Hence, from the whole of the experiments, these conclusions seem to be fully authorized:— That, in respect to the individual plate under examination, no unusual measure of the energetic magnetic development, which, from its position in the ship, it must have originally acquired, was retained; that the quantity of magnetic development it actually exhibited was devoid of any particular fixidity; and that no essential disturbance of its molecular magnetisms, calculated to give an effect of the nature of *permanent magnetism*, had been produced by the process of percussion and adjustment to the general fabric of the ship.

SECT. II. — *On certain* SPECIAL *and* PECULIAR *Influences, and the Principles of their Action, affecting the Magnetism of Iron-built Ships.*

AMONG the *special* circumstances, here referred to, (besides those already described and investigated,) which may be deemed to be capable of affecting the quality or extent of an iron-ship's magnetic condition and its alterations, we may notice, first, that of changes of temperature.

1. *Changes of temperature*, especially if partial or sudden, may be expected, I conceive, to exert

a sensible influence on the magnetic condition of an iron ship. In the experiments described in sect. vi., chap. III., of the foregoing part of our investigations, temperature, even within the moderate ranges of 10° to 20°, was found to have a very perceptible effect on the quantity of magnetism developed inductively by the earth; whilst heat, unequally applied, elicited, thermo-magnetically, a high and rapid alteration in the intensity of the polarity.

Hence, it may be inferred, and I think satisfactorily, that the *quantity* of a ship's magnetism (were all other things the same) should change with the alterations in the climates through which she might pass. But, where other circumstances are much more effective—such as the diminution of the earth's magnetic force in descending from polar into tropical regions—the changes from mere differences of climate could hardly be expected, I think, to admit of detection.

But changes in temperature of *partial application* to the ship's hull, may not unfrequently, I think, take place, such as are calculated to produce decided, if not striking effects. With respect to circumstances of this nature, I may refer to the unequal heating of the upper works of a ship by a strong action from the mid-day sun, whilst the portion of the ship which is under

water may remain at an uniform temperature. Or, referring to an influence which might act still more powerfully, perhaps, we may notice the special case of a sudden change in the temperature of the element wherein the ship floats. And this very case we find to be realized in the ordinary transatlantic passage from hence to the northern coasts of America,—where the ship, not unfrequently, may be found to pass through alternating streams or sections of cold and warm water, yielding changes of temperature to the amount of perhaps 20°, within an hour's or *possibly* within a few minutes' sail!

On this subject I had a very favourable opportunity of making satisfactory researches during a passage across the Atlantic to New York, in the spring of 1844, along with an American captain, of superior talent and intelligence, J. C. Delano, who courteously afforded me every opportunity for scientific enquiries. Among the various striking changes in the oceanic temperature, I find, by reference to a journal which I kept of the passage, the following records:—"In longitude 47° 39′ W. (latitude 42° 22′), the surface temperature was 62°; but on sailing 19 miles to the west it was found to have fallen to 45°." Again, in longitude 57° 32′ (latitude 41° 41′), after two hours' sailing, as noted in the log of May 17, the surface temperature of the sea

rose from 46° to 57°, or eleven degrees, within a space of 8 miles, and in the next two hours it fell again from 57° to 42°, or fifteen degrees, within 10 or 12 miles sailing. On May 18th, also, there was a rise in the surface temperature of fifteen degrees in two hours westward sailing, or a distance of 15 miles. And, again, on the 21st of May, when approaching St. George's Bank, the surface temperature fell from 58° to 45°, or thirteen degrees in two hours moderate sailing.

Under these rapid and extensive changes of temperature in the water—and, by necessary consequence, in the temperature of about one-half of the body of the ship whose material is iron,—amounting, for instance, to a change of 15° in a couple of hours, or less,—a very considerable effect, on the principles of thermo-magnetism, *should* be expected to be produced in the quantity of the ship's magnetic force acting on the compass. In our experiment recorded at page 140, on a cylindrical vessel of thin tinned iron, we find an increase of deviating action of a degree in the needle, for a change of about 15° temperature,—a quantity equal to a fifth-part, or more, of the entire magnetic energy developed by simple terrestrial induction! If a change, proportionate to this, should be effected by the unequal heating of the hull of a ship to the same

extent, the whole circuit of compass errors, it is obvious, may be increased in a similar proportion,—a proportion sufficient to render any previously determined allowances, or adjustments of antagonistic magnetic forces, perceptibly if not seriously erroneous. I speak, of course, under the guidance of theory and analogy only; observation and experiment on the actual cases will be necessary to determine *the extent* to which the influences referred to may be practically operative.

2. *A stroke of lightning* is another incidental influence, which might possibly operate so as to work great changes in the direction and energy of the magnetic development in an iron-built ship.

That a change in the general magnetic distribution would not be unlikely to occur, under such an incident—tending to yield conformity betwixt the ship's magnetism and that of the earth—we may confidently infer from our experiments recorded at pages 146 to 148. But this might not probably be greater in extent than the change ordinarily effected by a similar quantity of violence acting mechanically.

But, it is not impossible, if we may judge from certain cognate facts, that, in the event of a tremendous electrical discharge, betwixt the clouds and the sea, taking place through a ship's

medium, an *extraordinary magnetic development*, in the general structure, might be effected. As, for instance, in such a case as that of the American packet-ship New York, which was twice struck with lightning on her passage from the United States to England in the year 1827. It was during a thunder-storm encountered in latitude 38° 9′ N., longitude 61° 17′ W., which occurred at an unwontedly early period of the year, the 19th of April. In the first instance, which happened before day-light, the lightning stroke damaged the mainmast, started some of the planks of the bends, and produced strange devastation upon some of the cabin furniture and fittings. The weather continuing very unsettled and the air in a highly electrical state, with water-spouts in various directions around, a repetition of the explosion was dreaded by the captain. To meet such a perilous influence, protectively, a lightning-conductor which, providentially, was on board and ready for use, was elevated aloft. It consisted of a long rod of iron which was hoisted, by the signal-halyards, till its point extended upward above the truck at the mast-head, whilst from its lower end descended an iron chain communicating, outside the ship, with the sea. This contrivance, indeed, was the best in use until the admirably effective adaptation, by Sir W. Snow Harris, of a series of copper slips, let into the

mainmast, and extending below laterally, or otherwise, so as to form *an uninterrupted conductor, ever in its place and always ready for the electric storm*, betwixt the mast-head and the sea. The lightning apparatus of the New York, defective as it was in conducting capacity for a heavy discharge from the thunder-cloud, appears to have saved the ship; for in the afternoon of the same day a second electric stroke fell upon her mast-head, which, in its principal force, was carried off, though the conductor itself was destroyed, and portions of the chain fell in globules of melted iron upon the deck.

The magnetic effects of these tremendous electric discharges, which I had fortunately the opportunity of amply investigating on the arrival of the ship at Liverpool, were very remarkable. Almost every article I met with, capable of receiving permanent polarity, was found to be more or less magnetic. Table knives and forks, though lying at the time in a pantry considerably remote from the line pursued by the electricity, were capable of lifting needles or small nails, and one knife had the power of sustaining a travelling-trunk key. The ship's compasses were partially demagnetized, and most of the watches on board remarkably affected. The ship's chronometer was rendered useless for its object by the great alteration of its rate; and three or four

watches, whilst deposited under the pillows of their owners in bed at the time of the first shock, were stopped by reason of the high magnetic development in the steel pieces comprised in and about their works. Such was the intensity of their magnetism, that I found portions of the steel-work capable, not only of mutual suspension in pairs, but of sustaining a series of three or four pieces in a chain. One of these pieces, the cap-spring of one of the passenger's watches, which had been removed because of its *supposed irremediable damage*, I adapted to a light card as a directing-needle, which, when duly suspended, was found to act as a lively and excellent pocket compass, and so continues to act, with undiminished efficacy, to the present day!

Now what the effect of such an influence as this might be on the magnetic development of an iron-built ship, it is not pretended even to offer a conjecture. All that is designed to be suggested is embraced in the enquiry, Whether, under the action of an electro-magnetic atmosphere, so to speak, so influential and powerful as that by which the New York was pervaded, some influence, or, possibly, a powerful influence, might not be exerted on the general condition, as to magnetism, of a ship constructed mainly of iron?

If any powerful and generally pervading in-

fluence might thus come incidentally into operation, it might be further enquired, Whether the effects might not extend beyond the mere transient change of magnetic distribution, to a more permanent disturbance of the molecular magnetisms, and so to produce a character of fixidity in the magnetic development not ordinarily, or, perhaps, otherwise attainable? The assumption of the possibility of a change in the *quality* of the ship's magnetism involved in this enquiry, is founded on the case of the iron-bar which had been employed as an electro-magnetic (see page 225),—where a degree of fixidity was given to the molecular disturbance sufficient to resist, and that with a tenaciousness not in any other case realized in malleable iron, the effects of percussion, applied in aid of terrestrial induction acting conversely to the bar's polarity, which, ordinarily, had been found to exert so commanding a power.

3. *The permanent magnetism of the cast-iron* embodied in, and connected with, the machinery of ships propelled by steam-power, comprises another influence which, by possibility, might affect, peculiarly, the general magnetic distribution in an iron-built ship, as well as the operation of causes calculated to produce specific changes.

On the development of any special magnetic energy in cast-iron,—either by the position of

the castings (with reference to terrestrial induction) when the metal passes from the liquid to the solid state, or by the subsequent action of the chisel, borer, or other instrument productive of mechanical violence on the several portions of the apparatus,—no systematic experiments, that I am aware of, have yet been made. It is a subject, however, which would probably yield results sufficiently interesting to reward the investigator for any attention he might give to the special enquiry.

Though some degree of magnetic energy of the *permanent* quality might thus be elicited in the upright standards, cylinders, and other castings of a steam-vessel's machinery during the processes of fabrication, yet such permanent magnetism could hardly be exhibited, I think, in such amount as to be productive of any material disturbing influence on the compass at variance with the ordinary effects of the ship's general structure. And this we infer on two grounds:—first, because of the considerable distance, in most sea-going steamers, of the machinery from the steering or from the standard compass; and, secondly, from the chance of any permanent magnetisms which may happen to exist in the several castings, being so irregularly distributed, with respect to their separate polarities, as to neutralize, rather than strengthen, their general action.

CHAPTER VI.

PRACTICAL DEDUCTIONS AND SUGGESTIONS, FROM EXPERIMENTAL RESEARCHES, BEARING ON THE NAVIGATION OF IRON-BUILT VESSELS.

SECT. I.—*On the Adjustment of a Standard-Compass on an Iron Ship's Quarter-Deck, by compensating Magnetic Forces.*

WE have now reached, experimentally, the conclusion predicated at the commencement of this fourth part of our magnetical investigations; having determined, I trust I may say demonstratively, that the principles hitherto adopted for the compensation of the disturbing influence of a ship's magnetisms on the compass, do not reach the conditions requisite for a proper adjustment. For whilst the theory of the correcting-plate of malleable iron is,—that all the ship's magnetisms are, like that terrestrially induced, essentially mobile and dependent on position; the theory of the correction by means of permanent magnets combined with a mass of malleable is,—that the ship's magnetisms comprise a fixed or permanent quality, besides the mobile quality dependent on

simple terrestrial influence. Our investigations have abundantly disproved both of the assumptions on which the processes referred to are founded. Against the principle of the first, it has been shown, that besides the magnetism simply due to terrestrial induction, another quality of much higher energy, which we have denominated *retentive magnetism*, is necessarily developed in the process of construction of an iron ship; and against the principle of the second, it has been shown, that this quality of retentive magnetism, which, under particular circumstances, may *appear* to be fixed, is by no means of a permanent nature; for that no such quality as that of permanent magnetism can be found in the general material of an iron-built ship.

Hence the correcting-plate of malleable iron errs by defect, having no provision for the peculiar action of the ship's retentive magnetism; and the system of antagonistic magnets errs by excess, providing for the changeable action of the retentive magnetism by an unchangeable compensation. Whilst the former plan, therefore, must fail by not reaching the actual case, the other must still more dangerously fail by overreaching the original disturbance. And whilst the former, so far as it goes, should have the advantage of correcting a part of the compass deviation; the latter, going too far, — acting

fixedly on *varying* influences,—must, in the case of long voyages into southern magnetic latitudes, be liable to aggravate the natural deviation by the operation of magnetic forces no longer acting antagonistically, but in the direction of the original error!

To meet the conditions for a truly scientific and practical adjustment of the compass in an iron-built ship, therefore, the compensating magnetic influences must obviously be of the same nature and quality — of the same measure of fixidity, and of similar susceptibility of change— as those existing in the general substance of the ship. Hence we arrive at the principles on which, *if compensation for compass errors be practicable, that compensation must be made.* And contemplating the operation of the principles we have endeavoured to elucidate, no method of correction, it is obvious, could be effective that did not provide for changes in the antagonistic magnetic apparatus, equivalent to, and correspondent with, the changes in the ship's magnetism. A bar or plate of malleable iron, previously magnetized by percussion in a vertical position, and adjusted, by the tentative process, so as to act correctively on the ship's steering or standard compass, might possibly be made available for a general compensation for the ship's disturbing influence. But in order to its exert-

ing a consistent and corrective influence generally, and under considerable changes in the ship's geographical position, some degree of vibratory action might not improbably be occasionally necessary to be applied to it whilst in its fixed position,—especially on occasions when the ship's frame might be subjected to violent vibration or straining, accompanied by a change in the direction of her course.

On this principle of adaptation, might it not be possible still to apply Mr. Barlow's elegant contrivance of a circular plate of iron,—or something analogous to it, in the form of a broad flat bar, or of a circular ring,—so as to meet the conditions requisite for an effective compensation for compass errors? We have shown, in the foregoing researches, that the quality of retentive magnetism may not only be developed in circular pieces of iron, as well as in other forms, but that the axis of this retentive quality may be easily adjusted in any required position; hence it would seem not to be improbable but that, with this auxiliary quality of magnetism mechanically, or otherwise, developed, a contrivance of the nature of Mr. Barlow's compensating-plate might prove more effective and useful in navigation than any of the correctives heretofore devised.

In the use of bars of iron, however, as correct-

ing agencies of the ship's disturbing action, a still better approximation, perhaps, to a sound and complete system of influences might be obtained, by the adoption of three such bars, all duly magnetized by percussion, instead of one. One of them, according to Mr. Airy's suggestion for the application of antagonistic permanent magnets, would, in this case, be placed in a vertical position, proximate to the compass, another in a line parallel to the ship's keel, and another, laid also in a horizontal position, athwart-ships, or at right angles to the line of the keel.

The adjustment, indeed, of so many bars might present some difficulties; but not essentially greater than the plan of antagonistic magnets, and a box or mass of malleable iron. Their measure of effectiveness would of course be matter of experiment. That this plan *might* be made truly effective whilst the ship's magnetic condition should remain unaltered by the influence of mechanical action, hardly admits of a doubt; and that its effectiveness might be retained, even under the ordinary vibratory action of a steamer's engines, is by no means improbable,—since the correcting-bars might be made to sympathize in the general tremor produced in the ship's frame by their being supported, free from contact with other substances, by the ends or middle only. Under such an arrangement,

the condition, as to hardness, of the compensating bars, would require to be attended to. Probably they would require to be in the exact condition in which they were passed through the rollers, in order that the measure of retentiveness might correspond with that of the general material of the ship's hull. If this measure of consolidation should not be found sufficient—as the quantity of condensation by the hammering of the ship's iron might require something more—the compensating iron might, being made out of flat bars, be hammer-hardened.

Whether the sympathy of the bars in the ship's vibrations might suffice to yield correspondent changes in the retentive magnetisms of each, experiment only can determine. To experiment and observation, too, would need to be submitted the question of the requirement for occasional percussion, or other vibratory action, being impressed on the bars, in order that the magnetic changes in the bars might be kept in conformity with those of the ship's fabric. If, however, the retentive magnetism should be found to possess a much stronger measure of fixidity than our experiments might seem to indicate, then we might perhaps expect that the changes in the magnetic iron-bars, *spontaneously effected*, might avail for rendering them prevalently effective as correctors of the compass deviations.

In the application of these principles for the correcting of the compass deviations in iron-ships, there appears, I think, a reasonable prospect of obtaining, in due time, satisfactory results. At all events we may venture, with much confidence, to assume it as a conclusive fact,—that by no other mode than such an one, providing for all ordinary changes urged by mechanical vibration and violence, could the several varieties of a ship's disturbing action on her compass be reasonably expected to be met and neutralized.

SECT. II.—*Practical Suggestions in reference to the Determination of a Table of Corrections for the Standard-Compass.*

IN order to afford due facilities for the steering of a ship by a compass in immediate proximity with the tiller or steering-wheel, in which compass, the deviations, by reason of the quantity of ironwork ordinarily connected with the management of the rudder, may be unusually large, and, if two compasses are employed, irregular,—the plan of placing a *standard-compass*, for general reference, on the mid-deck aft, has become of somewhat general, and ought to be of *universal*, use in first class iron-built vessels. Its position is selected by a careful determination of where, amidships of the quarter-deck, there is the least

disturbance from locally-acting magnetic influences. And there (avoiding proximity with any iron standards or other powerfully attractive masses of the same metal) the standard-compass is fixed on a firm pedestal, and at a height above the deck sufficient for overlooking the ordinary railing, or hammock-boards, so as to observe, with the sight-vanes, the sun and other objects on the horizon.

As to processes for determining the deviations of the standard-compass, under the quiet swinging of the ship when in harbour, I have nothing original to suggest in addition to the "Practical Rules," published by order of the Lords Commissioners of the Admiralty. These rules, I may just notice, refer to the two most generally available methods in use:—that of observing the bearing of a distant object, whilst the ship's head is successively placed on each of the points of the compass; and that of the reciprocal bearings of the standard-compass on board and a compass on shore, whilst the ship, in the like manner, is swung round.

This latter process, it may be added, has been ingeniously modified by Mr. J. R. Stebbing, of Southampton. He places a centre staff with a distinguishing flag near the dockhead, and in the rear describes a semicircle of about 100 feet radius; on that circle every five degrees is

marked by a long pole with a flag, and each single degree by a short pole, the magnetic meridian having been carefully laid down beforehand. By observing the direction of the centre staff with any compass on board, as the ship is swung round, he obtains, by comparison of the compass direction and the true line of bearing as indicated by the poles, the exact deviation for each station. The series of poles, in fact, resembles a compass accurately pointing out the true magnetic directions, and on such a huge scale as to be easily observed from the ship.*

These processes, with the admirable addition to the Admiralty "Practical Rules" of Mr. Archibald Smith's "Instructions for the computation of a table of the deviations of a ship's compass from deviations observed on 4, 8, 16, or 32 points;

* An ingenious mode of exterminating the errors of the steering-compass, when thus determined, is found in Captain J. S. Sparkes' deviation-card. The errors ordinarily requiring special application to the courses steered, are here distributed over the compass-card by adjusting the several points, not in equal angles, but in angles comprising the sum or difference (as the cases may require) of the proper rhomb, or 11° 15′, and the deviation for such rhomb. This plan renders the course by the card (under proper adjustment) correct, or as correct as a table of errors. For change of deviation from geographical position, or other cause, however, it has no provision; a new card, or application of a table of special deviations, therefore, then becomes needful in order to its due effectiveness for the guidance of the navigator.

and for the adjustment of the table on a change of magnetic latitude," leave, as I have already intimated, very little to be desired further in regard to compass adjustments on the principles assumed:—that is, on the assumption of a ship's magnetisms comprising a large and permanent quality, retaining, under all changes of geographical position and without regard to the effects of mechanical violence, the polarity elicited in the ship's *original* structure.

If, however, the views heretofore set forth be correct,—as to the special magnetic distribution of each iron ship, as determined by her position whilst on the stocks, and as to the tendency of percussion or straining, after being launched, to modify the peculiar distribution or re-adjust it into conformity with the earth's magnetism,—then it must follow, that the tables of deviations determined by the processes referred to must soon cease to apply accurately as compass corrections, and that the deviations, as determined under the *quiet* swinging of the ship, *will not, ordinarily, be the best which might be obtained.* And it is to this latter particular that the "practical suggestions," indicated at the head of this section, have reference.

In order to a proper introduction of the suggestions I have here to offer, it will be convenient to revert, again, to the principles involved in a

ship's original magnetic distribution and its changes. These essentially are,—that the original magnetic condition and distribution result from the *augmentation* in quantity and *increase* in retentiveness of the earth's inductive action under the influence of mechanical violence employed in the ship's construction; and that subsequent mechanical violence, effected under changes in the ship's position, *tends* to reduce the existing magnetisms into conformity again with the new direction of terrestrial influences.

Hence it appears obvious, as we have already shown, that if a number of iron ships of the same size and lines, materials and strength,—in brief, fac-similes of each other,—were built on platforms yielding a different direction for the line of the keel, each one would have a circle of deviations (if quietly transferred from the stocks into the water) peculiar to itself. The deviations for each ship, therefore,—should the several ships be fitted out quietly, or without much heavy percusssion,—would represent an axis of magnetic distribution in an *extreme position* of obliquity, or peculiarity, out of which every variety of change of the ship's position, connected with vibration, percussion, or heaving by the sea, *would tend to the yielding of a distribution more conformable to the general medium.*

It is reasonable, therefore, to infer, that the

magnetic condition, as originally distributed by the building, is *the most unfavourable* for the determination of a table of deviations; as the extreme condition of the *special* distribution is more likely to change, and to change in larger quantity, than a medium condition subsequently elicited, either mechanically, or after the ship has been subjected to all the ordinary species of vibration and straining.

Guided by these considerations, it has appeared to me that, in the case of ships newly launched particularly, something might be effected, by the special application of mechanical action upon the general structure, towards the reduction of the ship's peculiar magnetic distribution into a more general or medium condition, so as, in such reduced condition, to obtain a better table of corrections for compass errors. To the practicability of such a result, all the investigations before the reader encouragingly point. It is not assumed, indeed, that the change of the original characteristic polarity could, by any ordinary application of mechanical violence, be thoroughly reduced to *a medium axial direction*, for no such result has ever been contemplated; but this only has been assumed, that *a* change, *tending* to such medium distribution, be the same considerable, or be it insignificant, must necessarily result from the application, in due measure,

of mechanical vibration or violence, if impressed on the fabric under new positions, adequately varied, of the ship's head.

By the expression "medium axial position," or "medium magnetic distribution," it should be noted, I design to indicate an arrangement of the ship's magnetisms equally remote from the characteristic extremes of any of the illustrated cases figured at page 269. A mean position of these four cases, it is obvious, would be represented by an axis of polarity vertical to the horizon, and an equatorial plane on a horizontal level,—a position precisely correspondent with what should be expected in an iron ship if built in the region of the northern magnetic pole. Now to such a direction or form of magnetic distribution, the changes in a ship's magnetisms which may be urged by mechanical violence,—whether on all the points of the compass in succession, or with the ship's head in the direction opposite to that in which she was built,—must obviously tend.

Hence, probably, the simplest mode of reducing the original axial position of an iron ship's magnetisms, into one of more medium character, would be by the application of a strong vibratory or concussive action on the ship with her head placed in the *opposite* direction from that in which she was built. Thus the ship re-

presented in our illustrative figure 14 (page 269), should be placed in the direction of figure 16 for the reduction of her special magnetic condition, and, in like manner, that shown in figure 15 turned round to the direction of fig. 17.

As to the mode of administering the requsite tremor or percussion on the ship's frame,—a variety of processes might obviously be employed. In respect to steam-propelled ships, the desired conditions might be most easily and satisfactorily obtained by placing the ship's head in a direction diametrically opposite to her position on the stocks during the placing of her engines, with their associate apparatus and fittings. From the quantity of percussive and vibratory action necessarily attending a work of this kind, a very considerable effect, tending to a medium magnetic distribution, I think, might be reasonably expected.

Mechanical action, in other cases, might perhaps be influentially impressed on the ship's fabric, by some special heavy percussion directed against stem or stern, or on any partial rib or plate of iron temporarily adjusted for preventing defacement of the proper structure; or by hauling a heavy floating body (such as a punt or lighter, or piece of timber,) into repeated contact, concussively, with the ship's side; or by the firing of cannon planted on the deck and secured

against recoil; or, in the case of steam-vessels, by a few strokes of the engine alternately with a direct and reverse motion of the propelling apparatus.

If the effects anticipated, in accordance with theory, should be found to take place to any considerable extent, the process suggested must unquestionably yield a better table of deviations, or a table liable to smaller alterations within the same limits of geographical positions, than could be obtained by the process of quiet swinging now in use.

The principles herein investigated and illustrated, have not, as I have shown, had that species of verification which the high importance of the subject, in a national point of view, deserves. If any of those who have the means at command (which I have not,) would put the principles to the test by actual experiments on iron-ships—the investigation, both in respect to its interest and value in navigation, would well repay the labour. And to the extent of trying the effect of vibratory or percussive action on the ship's hull during the process of swinging—the experiment might be easily made. Let the deviations of the standard-compass, for instance, be first taken in the usual manner of *quiet swinging*, and then let the process be repeated, applying the vibratory action at each station—

say at every angular interval of four points—and observe the deviation both before and after each application of mechanical disturbance. The differences of the two sets of observations, if any, would indicate the nature of the ship's magnetic changes.

A still better experiment might be made with an iron ship just after being launched. Let her deviating action, whilst very quietly swung, on a properly fixed compass as a standard, be first determined, and then, with the ship's head in the direction opposite to that which it pointed to on the stocks, let the hull be well and perseveringly vibrated by any convenient mode of application of mechanical force, and again let her deviating influences be ascertained: the differences, if any, would be conclusive both as to the measure and nature of the magnetic change produced by the mechanical violence under the new circumstances in respect to position.

Or, again, let the deviations of any iron steamship employed in our home coasting-trade be carefully taken at each terminal port in her ordinary voyage; at Glasgow, for instance, and Liverpool, or, perhaps, with a better adaptation of courses, at Glasgow and Belfast, or Liverpool and Dublin; and, if the changes predicated be real to any practical or observable extent, they must (after trial of a few cases) be detected.

In like manner the deviations of iron-built vessels (especially steamers), trading betwixt Hull, or London, and Hamburgh; betwixt Liverpool and New York, or Boston, etc., might be tried at each terminus of their respective voyages with a favourable probability of eliciting information calculated both to test the principles herein asserted, and ultimately to yield information of much value in practical guidance to the navigators of iron-built ships.

It needs hardly to add, that similar trials of the compass deviations of iron ships trading into more southern regions would be equally, if not still more valuable, as being calculated to yield better information on the extent of the changes ordinarily to be expected from changes in geographical position. But the testing of the principles developed in these investigations, and the determination of the extent of the actual changes in the magnetic distribution of iron-built ships, are the objects, mainly, to which, in this place, I would urge the attention of those who are practically engaged in the adjustment of their compasses.

It must not be overlooked, however, whilst thus appealing to the test of experiment, that our theoretical principles, however correct and general, cannot be expected to be always elicited in *apparently consistent* results. On the con-

trary, so prevalently will any compass referred to, as a standard, be found to be actuated by locally proximate influences, that the simple effect of the general magnetic distribution must be always liable to be, in some degree, merged in the more dominant attractions. Thus the compass, as we have shown, may be so situated, that the ship's magnetic forces *forward* and *aft* may be mutually destructive, and so leave the compass to the unembarrassed effect of terrestrial direction: or it may be so much under the control of some *upright* bar, standard, or other large mass or masses of iron,—exerting always in high magnetic latitudes a dominant action,—that the comparatively minor force of the *horizontally* acting iron may have no very observable effect, and so, *no change*, in respect to the deviations of that particular compass, may take place during any of the ship's ordinary voyages, though extending through a considerable range of distance within the same magnetic hemisphere. And whenever, indeed, the *vertically acting magnetisms* of a ship are mainly dominant, the changes we have predicated must be comparatively small, since the vertical magnetisms, being *terrestrially sustained*, can yield but little to mechanical violence, however severe, so long as the denominations of the upward poles remain unaltered.

It yet remains to be noticed, that every dis-

turbance in the equilibrium of the molecular magnetisms of the metal of which a ship is built, must exert a powerful influence on the *quantity* of magnetic change elicited by mechanical vibration. For although no particular disturbance of this nature was found in the plate referred to in the first section of chapter v., we cannot confidently infer that the whole of the ship's structure would be like it. If, therefore, any powerful disturbance of the molecular equilibrium should happen to exist, the effect, it is obvious, would be, not only to diminish the quantity of magnetic change, under influences of ordinary energy, but to give an increased measure of fixidity to the originally developed magnetisms, as well as a more rigid uniformity to the direction of the maximum deviations and "points of change."

SECT. III.—*The Correction of the Errors of the Binnacle Compass, on Scoresby's Method, by a Standard Compass aloft.*

OF all the processes hitherto devised for rendering the mariner's compass available for correct and safe guidance in ships having great local attractions, there is not one, that I am aware of, which, for facility of reference and accuracy in application, at all equals the simple plan of car-

rying a standard-compass aloft,—a plan which I adopted in years long gone by, and, during several of my latter voyages of adventure in the Greenland seas, invariably employed.

This plan, both as to its origin and general description, was published in the "Voyage to the Northern Whale-fishery" in the ship Baffin, in the summer of 1822. It is given at the commencement of chapter IV., pages 89 to 94, of that work, and is to the following effect:—

Considering the difficulties connected with the processes previously devised for the accurate determination of a ship's course, I was led to believe, "that a situation might be found at the mast-head, free from local attraction, where the deviation of the binnacle-compass might be at once ascertained by comparative observations, made independently of external objects." The application of this plan in the case of the Baffin —whose deviations were unusually large and irregular for a timber-built ship—was much facilitated through the medium of a *crow's nest*, erected, for the out-look and navigation of the ship when amongst ice, at the main-top gallant-mast-head. It had been carefully provided, that, in the construction of the crow's nest, and in the fittings at the mast-head to which it was secured, no iron-work capable of influencing the true action of the compass, should be introduced.

And, on the testing of the compass indications, by a series of azimuths taken at the mast-head on a variety of courses, such a striking measure of agreement was found—the greatest difference amounting only to a quarter of a degree, or the forty-fifth part of a *point*—that no doubt could exist but that the action of the needle was entirely free from disturbance by the ship's magnetism.

On comparing the indications of the binnacle-compass with the mast-head standard, the maximum deviations were found to be upwards of 8°, on a N.N.E. course, and about 17°, or rather more, on a S.S.W. course, with the points of change at E. *b.* S. and N.W., nearly, or, more correctly, at S. 82° E., and N. 49° W.

The process here so satisfactorily employed for determining the Baffin's deviation, might, it is obvious, be made generally applicable for the same purpose; and, in all cases of *sailing ships*, whatever might be the material employed in their construction, it could hardly fail to afford, I believe, a safe, if not a perfect, standard for the correction of the steering-compass. It is not assumed, indeed, that such a standard could be at all times, and under all circumstances, appealed to; for if so elevated a position, for instance, as that of the main top-mast-head were required, the swinging effect of the ship's pitching or

rolling would be likely to render a compass so situated only occasionally capable of steady adjustment. But if the elevation of either of the lower mast-heads should be found sufficient for the standard-compass, the measure of steadiness would be so much improved as to render it, except in heavy seas, very prevalently available for general reference. In either situation, however, whether the compass might be placed in one of the ship's tops, or near the top-mast cross-trees, occasions would not unfrequently be found—such as during calms or light winds, in harbour or in sheltered situations at sea—when either a set of deviations adapted for the correction of the binnacle-compass might be obtained, or its error on the course steered determined, so as to render this simple plan of signal utility in the general navigation.

During a discussion which followed the reading of a paper of mine at the meeting of the British Association at Oxford, in 1847, "On the Defects and Dangers of correcting Magnets for the Deviation in Iron Ships," in which I had urged the plan of a standard-compass aloft for the navigator's guidance,—it was well suggested by a gentleman present, whose name I unfortunately forget, that a compass so situated might be observed by means of a telescope from the deck. And, where the elevation of the lower

mast-head might suffice to free the compass from the ship's deviating action, or possibly in a higher position, this mode of observation—which would enable the officer of the watch to refer to the standard-compass without going or sending aloft—could be easily arranged for, and that simply, by attaching a telescope to the mast, or other fixed support below, near the deck, and having the standard indicator fitted something like a hanging-compass, so as to be observed from beneath.

This plan of a standard-compass aloft, it has been submitted above, would probably be found very satisfactory for all kinds of *sailing ships*, whatever might be the material employed in their construction. For *ships propelled by steam*, having short masts, generally, and a lofty chimney of great circumference, the applicability of the plan must, necessarily, be less effective. For whilst the shortness of the masts could afford but a comparatively low site for the standard-compass, the powerfully attractive influence of a huge lofty chimney of the ordinary construction, might still affect, to an inconvenient extent, the accuracy of the compass aloft.

In the case of one iron steam-ship, but not of the largest class, lying at the Broomielaw, Glasgow, I had the opportunity, in 1848 (assisted by Mr. James Napier), of making trial of the ship's

magnetic action in a position 32 feet above the cabin deck, and about half way betwixt the funnel and the stern. The ship's head lay about N. 60° W., and the quantity of the ordinary deviation being on a compass near the middle of the quarter-deck about 20°, was probably near the maximum. At the elevation referred to, I found 9° deviation (derived mainly, I doubt not, from the proximity of the iron funnel), and, seven feet lower down, 11° 38′.

This ship having but two masts, and these not very lofty, did not afford a favourable case for determining the effects of elevation in relieving the compass from her magnetic action. In the larger class of vessels, however, having three or more masts, a position much more remote from the chimney would be found appropriable for the site of the standard-compass. And, were the importance of the object duly estimated, it might be deemed worth the expense, possibly, of getting rid altogether of this formidably disturbing influence by substituting the material of *copper* for iron, in the construction of the funnels of sea-going ships. But even, under the existing system, by planting a mast pretty far aft, a place for a standard-compass might generally, I think, be found, whereby great additional safety would be secured for the navigation of the vessel.

It should be further observed, in respect to

the performance of a compass aloft, that not only must the general deviations be necessarily *reduced*—in many cases, I believe, to such an extent as to become of small importance—but the operation and changes of particular local influences acting on the deck compasses, would be likely, in the more general influence of the ship's fabric on a compass so raised above it, to become insignificant, if not totally to disappear.

Whilst, now, the plan we have suggested for the adjustment of a ship's deviations by a standard-compass aloft, is found to be truly perfect in timber-built sailing-ships, and, I doubt not, would be found quite satisfactory in iron-built ships of the like class; it could hardly fail of being found a valuable help to the navigator, if carefully and properly ordered, in any kind or class of sea-going ships whatever. And it would only need the determination of the existing errors by any of the effective processes in use, with such checks and corrections as the state of the sea and weather might occasionally afford, in order to render the indications of the standard-compass aloft, in the highest practical degree, perfect and safe. And at all events, and under any limited extent of remaining defectiveness, this special recommendation would, I believe, invariably attach to the plan — *that much, tending to safe guidance, would be gained.*

It hardly needs to be remarked, that where such an arrangement as this proposed might be contemplated, it would be necessary to exclude every form of iron, whether of cross-trees, bolts, straps, chains, or hoops, from the immediate proximity of the platform or site designed for the compass,—substituting for these now very usual iron fittings, wood, rope, or copper, as, according to each special case, might be the most convenient or economical.

Sect. IV.—*On the Determination of the Deviation by Colonel Graydon's "Celestial Compass."*

An ingenious compass, invented by an amiable friend, the late Colonel Graydon of the Royal Engineers, affords, perhaps, the easiest and generally most available means of determining the true meridional direction on shipboard, of any instrument or process, *dependent on celestial observation*, yet devised.

The *celestial compass*, as this admirably arranged instrument is named, consists of the adaptation to the usual mariner's compass of a series of moveable circles and arcs so contrived as to exhibit the plane of the sun's motion, and to indicate the place of the sun in azimuth, at the moment of observation.

For the attainment of these objects, an *hour-*

circle, moveable on a horizontal axis fixed at right-angles to the meridional position of the instrument, is adjusted (by being elevated at the southern edge to an angle equal to the complement of the latitude) into parallelism with the earth's equatorial plane; whilst a *declination-arm*, traversing on the hour-circle, when duly adjusted to the sun's position, necessarily describes (if the compass be in the true meridian) the plane of the sun's motion. The effect of these arrangements is such, that a speck of light, from the sun's rays passing through a lens at the extremity of the declination-arm, is thrown exactly upon the middle of two cross-lines drawn on a disc at the centre of the instrument, whenever the compass, with the declination-arm pointing to the apparent time on the hour-circle, is correctly placed in the true meridian.

Hence we may perceive the principle on which the celestial compass acts. As, on the due adjustment of the instrument for latitude and declination, the arm with the lens, when directed to the sun, must throw the speck of light exactly on the middle of the central disc,—if it be in the true meridian,—it necessarily follows, that, if the speck fall either above or below the centre, the position of the instrument is *not* truly meridional. In practice, therefore, on effecting the required coincidence of the

speck of light and the centre of the disc, by a vertiginous motion of the instrument on its general axis, the true meridional direction is determined,—for this coincidence will not take place except when the azimuth of the sun in reference to the instrument, is the same as that of the sun in reference to the earth, or except when the plane described by the observing arm of the instrument is coincident with, or parallel to, (neglecting the trifling variation from the progressive change of declination,) the plane of the sun's motion.

By comparing, then, the course steered by the binnacle compass, with the true meridian pointed out by the celestial compass on ship-board, the variation and deviation, conjointly, will, under existing circumstances, be correctly exhibited, or (which is the matter of essential importance) the *true* direction of the ship's head will, by direct observation, be at once determined.

It is somewhat singular that an instrument of such ready and important capabilities should not have come into more general use. It is true that it is not—as no compass employed at sea can be—*a perfect instrument.* The accuracy of its indications is obviously dependent on the horizontality of the plane at the compass-rim, in reference to which the horary circuit is described. This horizontality is secured, however,

to an unusual degree of nicety, by a peculiar arrangement of the gimbals, with a careful adjustment of the various points of suspension both of the compass-bowl and card. And when experimentally tested, these arrangements have proved remarkably satisfactory. Thus, even in a very inferior construction of the instrument to that at which the inventor had ultimately arrived, its action was proved to be so effective, practically, as to gain for it a high degree of approbation in the reports of several naval officers to whom, at different periods, the celestial compass had been entrusted, under sanction of the Lords Commissioners of the Admiralty, for trial.

The celestial compass, it should be further noted, is designed for solving a variety of problems in nautical astronomy—such as the determination of the *true time*, to a very useful extent of accuracy; the *latitude* of the ship, proximately, probably, to two or three miles; the *altitude* of any of the heavenly bodies; the azimuth or amplitude of the sun,—as to the whole of which, the reports referred to indicate, that the instrument was found—quite independently of any direct reference to the visible horizon, and without calculation—to act usefully and satisfactorily.

SECT. V.—*On certain Schemes for insulating the Compass, and intercepting the Ship's deviating Action.*

THE idea has been suggested, and somewhat extensively entertained, that it might be possible to intercept the magnetic influence of the vessel, and so cut off its deviating influence. It would not have been necessary to refer to a notion so adverse to the principles of sound science, had not a variety of compasses been contrived and actually constructed (of which there was an example in the late Great Exhibition) on plans assumed to have in themselves elements interceptive, or corrective, of the ship's attraction. That no such means could possibly avail for the end designed, even if a material could be found capable of exerting the imagined power, is obvious from this simple consideration,—that the medium which would intercept, or neutralize, or distribute the ship's magnetism, must produce the same effect on that of the earth. So that the substance which should avail in stopping the one influence, must effectually stop the traversing of the needle. But, as we have good reason to believe, there is no substance in nature which has any such influence. On this point, very extensive personal investigations, made many years ago, tended to show,—that all substances

are transparent, so to speak, to the magnetic influence. And neither masses of iron, either in the metallic or mineral state, nor even powerful magnets, were found to have the smallest power to arrest this mysterious and subtle agency. Magnets and iron, indeed, modified the effects of other magnetic substances, by the mutual and reciprocating influences upon one another; but the directive influence of a powerful bar-magnet, on a compass placed beyond large masses of iron, or large and powerful magnets, was found to be as energetic, though not so easily analysed, as if no such bodies had intervened.

An amusing incident connected with these researches, may here be mentioned. It occurred whilst I was making experiments on the transmission of the magnetic influence through various solid materials, and to considerable distances, at the Liverpool station (the original terminus) of the Liverpool and Manchester Railway. The object under trial was one of the locomotive engines standing in the building appropriated for repairs. I had placed my compass on one side of the engine, and a powerful bar-magnet of two feet in length on the other—in a position in which the magnetic influence had to penetrate through the various plates of metal constituting the cylinders and fireplace. There were about eight thicknesses of iron in the line of transit.

Two workmen, who happened to be in the place, came to look at the process in which I was engaged — watching, with animated intelligent curiosity, the motions of the needle of the compass when I changed the position of the magnet. Observing that whenever I turned the poles of the magnet, the needle was deflected from the direction it had previously assumed, one of them, addressing his comrade, uttered the intelligent exclamation, "Why, Tom, it sees through 't!"— a description of the phenomenon which was singularly characteristic.

SECT. VI.—*Practical and cautionary Suggestions for the Navigation of Iron-built Ships.*

A conclusion of great practical importance, to which the foregoing investigations obviously and prevalently point, is, the *general instability* of a considerable proportion of the existing magnetisms in an iron-built ship. Under alterations of the course steered, and especially under changes in magnetic latitude, the effect of vibratory or straining action on the general fabric of the ship, must necessarily, it would seem, be productive of changes, more or less important, in the compass deviations.

Embarrassing as this consideration may, at first sight, seem, it is nevertheless calculated to

yield a rule of *special caution*, for the navigator, whenever such circumstances have come into coincident operation as, on ascertained principles, are likely to produce special changes in the ship's magnetic distribution. For the very conviction, in itself embarrassing, that the deviating action on the compass *may have suddenly changed*, will, at all events, lead the prudent commander, when nearing any position of danger, to the exercise of a *cautious watchfulness*, which, after all, under the Divine providential care, is the seaman's best safeguard.

In offering now our proposed practical suggestions for the navigation of iron-built ships, it will be convenient to cast them into several distinct or separate portions.

1. In whatever manner the compass may be adapted for practical guidance — whether by adjustment with magnets, or by a table of errors, or by Sparkes' deviation-card—let it be always borne in mind, that *neither adjustments nor corrections can*, for *all* courses when at sea, *be exact;* and that however practically correct the compass, in an *outward* voyage, may prove, it by no means follows that it will be equally correct on the *homeward* passage.

In a steam-propelled ship proceeding on a distant voyage, the compass, after an uniform

course has been for sometime pursued, may be expected to keep a steady direction, subject only to the slow and gradual change belonging to change of magnetic latitude. And if sailing from a British port, or other higher parallel of north latitude, the effect on the compass of change in geographical position, would not probably be very conspicuous, within any of the regions northward of the Tropic of Cancer. The occasions for watching for or expecting alterations in the compass adjustments, would be *on change of course*, or, after a long progress in a smooth sea, *on encountering a heavy gale.*

Thus, in the case of a ship proceeding from a northern country into a tropical or southern region of the globe, little danger would probably arise from change of the deviations so long as a continuously straight course might be steered,—at least the change, so far as important, would be likely to show itself, by discrepancies betwixt the ship's reckoning and place by observation, or otherwise, during the progress southward; but on suddenly hauling up on a course of considerable obliquity to that which had long been pursued, either on the passing of some headland, or in following some coast line in a new direction, the navigator should then be specially watchful and suspicious of his compass guidance. He ought not to expect, however provision for such

changes of course may be ostensibly made, that his compass indications can be safely followed. A *wide berth*, therefore, should be given at night, or in thick weather, to any dangers lying in the way, as allowances, which would be ordinarily safe for timber-built ships (the changes of whose deviations may be so much more easily anticipated), might be *fatally* inadequate for the security of a ship built of iron.

In regard to vessels regularly and repeatedly running betwixt the same terminal ports,—such as our coasting steamers, especially, or the steamers betwixt British and foreign ports, performing their voyages in a few days, or repeating them many times a-year,—the commander, rather than defective compasses, is to be held answerable for mistakes in the course pursued. For the advantage of the compass, and its availableness for safe guidance, must in these cases, particularly, depend, not so much on the accuracy of the instrument, nor on any anticipatory adjustments, as on the careful observation of the intelligent navigator, when passing from place to place, or from headland to headland, of the course actually made by his own compass in each part of his progress, and in each passage of his voyage, outward and homeward. Such observation, regularly attended to, will soon show—in what portions of the voyage

the compass acts consistently with itself, and in what portions its action is irregular; whilst the entire experience will tend to the important practical result of a satisfactory confidence as to where the compass is always consistent, and a salutary distrust as to where it is liable to mislead.

2. For determining the errors of the steering-compass at sea, and the corrections to be applied, —the plan of *a standard-compass*, placed clear of the general action of the ship's magnetic influence *aloft* (as suggested in sect. III.) appears to me to be the safest, most easily appealed to, and, on the whole, the best arrangement.

Next in availableness to this, and important also for the verification of the mast-head compass, is a reference (the more frequently and better) to azimuths of the sun. Let the azimuths be taken, on the plan usually recommended, when the sun is at a somewhat low altitude, in sets of three or more observations of the compass, marking specially the observations on which the ship's head was most steadily kept on the proper course. It will conduce to accuracy, too, to take separate sets of the sun's bearing and altitude with the ship's course altered, say a point on each side of the course.

In sailing vessels, opportunities will not unfrequently occur, when, by reason of light winds

not admitting of much progress in the voyage, sets of azimuths, on the plan just suggested, may be taken for the full range of courses which the ship may probably have occasion to pursue, without involving any material loss of distance. And thus might the observations be made available for the correction of the table of compass errors, to an extent of sixteen to twenty points if required. In steam-propelled ships, the same object, as far as may be required for their less varied courses, may be also effected easily, and advantageously to safety, whenever the sea is pretty smooth, on the nearing of land. To proceed for a few minutes at a relaxed speed, whilst azimuths should be taken on two or three courses, could produce no such sacrifice of time as would be ordinarily appreciable on the length of a distant voyage.

In case of the longer process of observation in a sailing ship, when a considerable series of deviations may be taken, it would not be generally necessary to calculate the azimuths for each course separately; but an altitude at the beginning and end of the whole series might do, and the true azimuths calculated for these extremes. The proportion of the interval of the mean of each set, to the interval betwixt the times of the calculated azimuths, would be sufficiently accurate for the adjustment of the sun's true bearing

for each course. The errors of the compass thus ascertained for three points or rhombs would give—not by the mean indeed, but by comparison, proportionally, with the changes in the original table of compass errors—a more accurate result for the error on the course steered.

3. The careful navigator will embrace every favourable opportunity, when at sea, of *determining the compass error, or the true direction of the ship's head, on the course steered.* It is not wise to conclude, though the ship may be abroad in the wide ocean and far from any land, that any possible error of the compass is of no consequence; that it may be corrected by the next day's sights for chronometer and latitude; or that, if not then corrected, it will involve no danger. For all determinations of the compass errors are useful; and even those which are obtained far from land may aid the judgment in steering when near to land. All such determinations, moreover, will serve either to give a proper and useful degree of confidence, where the errors are found to be uniform, or to suggest a due exercise of caution, when such errors may prove to be variable.

4. A separate and careful *register* should be kept *of all observations for the determination of*

the true direction of the ship's head. This ought to include—latitude and longitude, course by binnacle and standard compass, true course as determined by azimuth, quantity of variation, if known, and compass deviation on such course. To these particulars, with much advantage might be added, the state of the sea, or whether the ship was going smoothly or under much motion, and the *length of time* in days and hours, or days and decimals, on which the course then steered had been pursued. A blank page, opposite each page of ruled form, would be desirable for the captain's remarks on the observations made. He should note thereon any discrepancies he may, in any case, perceive; any facts or peculiarities which his observations may have happened to elicit, with references to deviations from his table of compass errors, or differences in comparison with compasses adjusted by magnets, etc. And, we would further suggest, that *each case* of good and satisfactory determination of the compass error, should be made the subject of comparison and consideration *at the time;* for it is far easier and more effective to make such deductions at the moment, than it would be after the special circumstances were reduced to the bare figures noted down in the journal.

5. In like manner it would subserve important

practical ends to keep a record in, or separate from, the daily log or journal, of *the differences betwixt the reckoning and the positions determined by observation.* And youngsters would be well employed in any of the larger foreign-trading ships or packets, in calculating the course made good each day, both from observation to observation, and from the mere reckoning. The differences, being daily noted, and compared at longer intervals, would hardly fail to indicate, whether these were incidental, proceeding from bad steering, or errors in the log, or from *incorrect* allowances for compass errors and influence of currents. In most cases, however, where the daily run was considerable, the chief element of error, except in regions known for strong currents, would be referable to the compass. In this record, too, it would be worth the while of the enquiring or scientific navigator, to separate *the entire run on each particular course*, whether continued for hours or for days or weeks, and calculate the true course and distance (on the ordinary plane-sailing principle might do) as given by celestial observations, and also as continuously given, without intermediate adjustments, by the dead reckoning. These results given in a tabular form, should embrace dates and intervals of time (days and hours) for each course; latitude and longitude started from (being the same for both modes of

reckoning), and latitude and longitude terminated in, comprising the separate results of observation and dead reckoning; the compass-course steered; the true course and distance made good, as derived both from celestial observations and from the dead reckoning; with the differences betwixt the last two sets to show the errors in the course and distance of the dead reckoning.

Such particulars, exhibited in a clear and compendious form, could not fail to yield results which would at once be of real and essential utility for the safe and satisfactory navigation of the individual ship, and, to the navigators of ships of the build and construction to which our remarks more especially apply, generally important and beneficial. And among the prominent results for which, in accordance with the anticipations suggested in the foregoing pages, we should look, would be peculiar changes in the deviations, as originally determined before sailing, on sudden or considerable changes of course, or after heavy pitching or rolling in gales of wind; changes in the general character of the deviations, or failures in effectiveness of any correcting magnets, or in applicability of tables of compass errors, after passing far into another magnetic hemisphere; differences in the nature or quantity of the deviations,—comparing observed deviations when at sea with those deter-

mined in harbour,—betwixt the voyage or passage *outward* and that *homeward;* and, *possibly*, alterations in the ship's magnetic condition in highly electrical states of the atmosphere.

6. We may conclude these practical suggestions, by refering the wise and reflective navigator to *the grand and essential source both of his prosperity and safety.* For after all that prudent watchfulness and practical skill can accomplish for the safety of sea-adventurers and adventures —for every voyage, coasting or foreign, is more or less of *an adventure* in which life and property are perilled—the confidence and consolation of the thoughtful, and the ultimate security of all concerned in the risks must rest, religiously and rationally, *on the Divine Providential care.* In the personal character and abilities of the commander of a ship are found the leading sources of confidence in the promoters of commercial undertakings. And when with experience and talent, with sobriety and integrity, with courage and circumspection, are associated the religious esssentials belonging to the highest attainable endowments,—we have, in such combination of character and practical qualification, everything, so far as man may anticipate, that may conduce both to the safety and prosperity of our maritime enterprises. For whilst those, in a special

manner, "who go down to the sea in ships, that do business in great waters," are said to "see the works of the Lord and his wonders in the deep,"—they are in a manner equally special shown by the written declarations of our holy faith, that when "they cry unto the Lord in their trouble," they are encouraged to hope for deliverance "out of their distresses." It is not to be assumed, indeed, that a religious character could subserve for knowledge and experience in the navigator, much less that the principle of piety, without the practice of seamanlike conduct, could be expected to avail for safety; but that the two qualities combined, ought to co-operate, and, when co-operating, must yield the most favourable conditions for superior guidance and management in nautical adventures. The commanders of sea-going ships, it is obvious, cannot *all* be men of talent; but there is no one who may not aspire to, no one who ought to be content without, the attainment of the true religious character. And though such an attainment may not yield a talent beyond that of the natural constitution, it will give direction to existing talent for the exercise of its best capabilities; so that with the advantage of a prayerful and special looking to the Divine guidance and the reasonable expectation of assistance therefrom, the pious navigator should in all respects be

better qualified for encountering the adventures and perils of his profession, than one who, devoid of the fear of God, relies solely on himself.

The ability and character of the captain, as bearing on the general safety of the ship, is a matter of such great and obvious importance as to be looked to with a considerable degree of scrutiny by the most intelligent underwriters. Thomas Chapman, Esq. of London, Chairman of the Committee of Management of the Society, in connection with Lloyd's, for classing British and Foreign Ships—a friend to whom I have been many times indebted for valuable information on subjects connected with his department of commercial enterprise—in writing on this subject observes, that a high measure of importance, as to the terms of a sea-risk, and confidence in taking it, is attached to the *character of the owner*,—a well-known and favourite owner, that is one who is so characterised because he sends out substantial ships, liberally found and *well commanded*, obtaining a decided preference and, not unfrequently, an advantage in premium. And speaking of the circumstances which affect the comparative safety of ships of different qualities, Mr. Chapman adds,—"what an important element is the *seamanship* of the *master*: in a trying position the skill of the captain may save the *inferior* vessel, whilst the *superior* is lost from the want of it."

In respect to the qualifications which conduce to the character of a *superior seaman*, I would here take occasion, by the way, to notice and commend that old-fashioned but excellent quality of *prudence* or *caution*, now, unfortunately, so moderately estimated. For it would be well for the public safety, as well as for the economising of property in maritime adventure, if the *excessive anxiety for progress and dispatch* of the sea voyage might be reasonably controlled and restrained against the braving of unfitting risks. The adventuring on perils without either necessity or call of duty, is always a questionable undertaking; whilst recklessness of danger is the characteristic, not of courage or true manliness, but rather of fool-hardiness. The making of *short cuts* by adventurous risks—the hugging of the land when the actual position of its rocks and shoals cannot be clearly ascertained,—is not only a professional error and folly, but, on principle, a fault—a wrong. If it were lawful in a navigator to run extraordinary risks with his own life and property, that would not justify him in recklessly imperilling the lives and property of others. But if the former act be unjustifiable, the latter must be a *moral delinquency*. Yet is this species of delinquency too lamentably prevalent. For to *the excessive haste* (as if it were the order of the day) to accomplish

the voyage—to the pride and stimulus of competition in the run—to the morbid dread of losing a few miles of distance, within a given time, or a knot or two of speed,—may, I doubt not, be ascribed that loss in steam-vessels, which, considering their various advantages for comparative safety, has in some years, of late, been so disproportionate if not exorbitant.

In summing up the suggestions which have occurred to me as bearing most essentially on the safe navigation of ships built of iron, I find them practically resolvable into about half-a-dozen directive or cautionary rules. These, that they may be better remembered by such navigators as may appreciate their fitness and importance, I have cast into the following somewhat rude rhymes:—

The *watchful out-look* let not cease;
Nor *observations* ever miss;
Be of *compass changes* wary,
Running *near to dangers* chary;
On *duty personally* attend;
On Providence, Divine, depend.

CHAPTER VII.

CASES, INCIDENTS, AND EXAMPLES, AS TO IRON SHIPS, ILLUSTRATIVE OF, OR ELUCIDATED BY, THE PRINCIPLES DEVELOPED IN THE FOREGOING INVESTIGATIONS; WITH CASES OF CALAMITOUS SHIPWRECKS, REFERABLE TO THE DEVIATION OF THE COMPASS.

SECT. I.—*Elucidation of certain peculiar Disturbances or Irregularities of Compass Action on Ship-board.*

1. IN returning from the United States of America, in the spring of 1848, on board of one of the Cunard line of admirable steam-packets, I was struck with a remark of the captain (corresponding indeed with what, under somewhat analogous circumstances, had been observed by others) in respect to an anomalous action he had several times noticed in his binnacle-compass on passing, on the homeward voyage, one of the prominent headlands on the southern or south-eastern coast of Ireland. On rounding such cape, he remarked, the compass, not unfrequently, was singularly disturbed, — the card

swinging widely, and sometimes going quite round.

It might be thought possible, perhaps, that the peculiar character often assumed by the waves near certain prominent headlands—of the nature technically designated "a short jump of a sea"—might be the occasion of an extraordinary disturbance in the compass-card. But the limitation of the disturbance in the ship referred to, to this one particular position, renders such an explanation, I think, unsatisfactory. Another explanation, however, depending on a peculiar combination of magnetic influences, has been suggested by the researches described in a former chapter, which appears to me to be far more probable. The peculiar influences to which we allude were those met with in the examination of the magnetic condition of the Simoom (see page 280), wherein the magnetism of the ship, in one case, acting antagonistically to that of the earth, happened so to neutralize the ordinary directive energy, that the compass-needle became liable to deviate in slow and wide oscillations, or to turn, like an unmagnetic needle, round and round.

Might not something like this combination of opposing influences take place in the ship referred to? The steering-compass was, in the case of the packet-ship, very far aft, and was placed

within a wheel-house greatly encumbered with chains, standards, and other articles or masses of iron. If now any of these proximate masses of iron should be so situated, with respect to the compass, as diametrically to oppose the earth's directive action when the ship's head was on a particular rhomb, say north, or north-easterly,—then, on changing the course into such particular direction, the compass would necessarily traverse with diminished energy; and the diminution of force *might* be such as, in the experiment *within* the Simoom, to cause the needle to oscillate widely, or possibly, when much disturbed by the ship's motion, to whirl completely round.

2. Another peculiarity in compass disturbances, which our investigations serve, I think, well to elucidate, is the occurrence of an anomalous deviation on the passing of certain headlands. In many cases, this phenomenon, according to the popular idea concerning it, is reasonably ascribable to the magnetical action of volcanic rocks; but in other cases does not seem to occur except in the compasses of iron ships. For instance, the captain of the Pacha, one of the Peninsular and Oriental Company's steam-ships, had noticed, as I was informed when making enquiries on this subject at Southampton, that his compass, with "corrected card," acted well,

except from Cape St. Vincent to Cape Trafalgar, where there was an anomalous error of about a quarter of a point.

Now this anomaly, varying from the ordinary changes of the deviation, is precisely of the nature of what I have been led to anticipate in cases, just like this, where an iron ship, having for a considerable distance pursued a tolerably uniform direction, turns in a new direction at a considerable angle with her previous course. For in accordance with the principles considered in section II. of the preceding chapter, and illustrated in our Results, page 333, a ship steaming, as in this example, a distance of 700 to 800 miles in a direction prevalently south-westerly, should gain such a measure of fixidity in her retentive magnetisms as, on suddenly changing her course to the south-eastward, should resist for some time the restoration of the general deviations to their ordinary and medium action.

A like sudden change has been repeatedly noticed by Captain Moresby, of the Ripon, on passing Cape Bon, near Tunis, (as well as in some other positions on the coast of Africa, where a change of course was made,) the variation suddenly altering four or five degrees, and after some days, perhaps, occasionally after a few hours, subsiding into the more ordinary condition. Such alterations were specially remarked

in the voyages of the Ripon betwixt Southampton and Alexandria, on the outward passages in March, 1848, and February, 1849; also on the homeward progress in the several passages performed in March, May, July, and September, 1848.

SECT. II.—*Examples of the varying Action and Discrepancies of "Adjusted Compasses," illustrative of Theory.*

THE experiments undertaken in connection with the "adjustment of the compasses" in iron ships, serve amply to demonstrate the truth of our position enunciated at page 265, that, in respect to the precise action of the compass, every ship is a case by itself. Hence, under certain general principles of accordance, it is found, that in some ships the amount of magnetic disturbance on the binnacle compass is very large, equal to half a right angle perhaps; in others very small, occasionally hardly sensible. In some, "the points of change," or the directions in which the compass is correct, are found when the ship's head is north and south; in others, on various points obliquely from such directions. In some, the deviations have their two maxima pretty equal and on opposite points; in others, the maxima are very different in amount and equally

inaccordant with their distance from the points of change. Finally, in some, the dominant magnetism of the ship, acting on the compass, has southern polarity forward, or obliquely forward; in others, northern polarity in the like position with southern aft.

Hence it may be inferred, in accordance with the views stated in chap. III. sect. I., and chap. IV. sect. I., that where the mean action of the innumerable magnetic forces in the ship is so infinitely varied, both in quantity and direction, the *effect of changes* in the ship's general magnetic distribution must be also correspondingly different.

An investigation, though but to a limited extent indeed, which I had the opportunity of making personally at Southampton, in the month of April, 1850, served at once to verify the diversities indicated by theory, and to enable me to elucidate various pecularities and anomalies by the application of principles previously determined. Under the obliging facilities afforded me by Captain Engledue, of the "Peninsular and Oriental Steam-Navigation Company," and under the guidance of Mr. Stebbing, the manager of the compass department, I was enabled, whilst visiting a number of their ships which happened to be in port, to gather a variety of facts bearing upon the general object of my

enquiries. Among the ships visited on this occasion were the Pottinger, Ripon, Sultan, Pacha, etc., etc., with the captains or chief officers of which, generally, I had the opportunity of conversing. Each of the methods of adjustment of the compasses, then in use, had, I found, been well and considerately applied by Mr. Stebbing to the iron-built ships under his management;—thus, "correcting magnets," tables of deviation, and Sparkes' adjusted card, were not only severally in use, but, in some ships, two, if not all the methods were employed. And, where antagonistic magnetic forces had been adopted, it appeared that a single magnet, by itself, had sometimes sufficed for the requisite "correction," whilst in other cases two magnets, or two magnets with the addition of a box of chain (to complete the apparatus of Mr. Airy), were deemed requisite.

The result of the various modes, in regard to their practical efficacy, was somewhat curious. For among the cases where the compasses were reported to have acted "correctly," or "quite satisfactorily," some had adjusting magnets with malleable iron, some a magnet or magnets without the iron, some correcting magnets *with* table of *uncorrected* errors, and some only Sparkes' deviation-card.

Thus in the *Pottinger*, both in the southern

hemisphere and in the Mediterranean, the corrections by Sparkes' card had been particularly approved; in the *Sultan*, in the latter region, correcting magnets *with* a table of *uncorrected* errors, had given much satisfaction; in the *Pacha*, and also in the *Madrid*, the mere deviation-card had acted quite well; and in an iron vessel engaged in running to and from Havre and the Channel Islands, the compass was reported to have performed its office well without any adjustment or allowance whatever!*

But with so many approving reports of the practical results of the processes adopted for the compensation of compass errors, I found various examples of *defectiveness* and *change*. In the case of the Sultan, with magnets and a box of chain connected with the compass, a residual error of 9° to 11°, at a maximum, had to be corrected by a table of errors; whilst some other ships' compasses, acting well at home, were found considerably out at their foreign destination.

But it is to the circumstance of *change* in the compass action, into which, as one so much insisted on in the previous pages, I have now most particularly to refer,—such as change *be-*

* In the analyzing of the notes taken on my investigations at Southampton, I have been assisted by a letter of Mr. Stebbing's, on the compasses of iron-ships, published in the "Artizan," of August 1850, which has afforded, too, some additional information of which I have availed myself here.

yond what had been deemed to be referable to new geographical positions, and change incident on *time and sea-employment* in the same general geographical position.

In the case of the *Wonder*, trading betwixt Southampton, the Channel Islands, and Havre, where corrected compasses had at first acted well, a change to the extent of about one point, maximum error, had subsequently taken place. In that of the *Indus*, swung in July 1848, an alteration in her deviation, after about twenty months, was found to have been produced to the extent of near half a point. In the case of the *Ripon*, a change to a similar extent, within the range of our home coasts, was found to have taken place. But it is matter of general observation, I believe, with those engaged, practically, in the adjustment of the compasses of iron vessels, that the original deviations change with time.

As to the differences of the deviation in England, and in regions 15 or 20 degrees further to the southward, we have an example in the Sultan's compasses, as mentioned by Captain Brooks, who found a change of four degrees betwixt the errors at home and in the Archipelago. Captain Soy of the Indus, quoted by Mr. Stebbing, found a change of like amount on swinging his ship at Alexandria.

These facts, limited as they are in number of

special cases, very well illustrate the views set forth at page 371, respecting the change which, theoretically, should take place in a ship's original and extreme *direction* of general magnetic action into a position more conformable to the medium axial condition; as also of the modifying effects of changes of geographical position on the ship's magnetism of the *retentive* quality.

As to the occurrence of apparently anomalous changes in the deviation—the cases I have been enabled to enquire into afford many examples.

Thus, in the case of the Ripon, on her voyage from Alexandria, homeward, in the month of May 1848, I find in Captain Moresby's compass observations, with the register of which I have been kindly entrusted, the following note respecting an anomalous action of this kind which occurred on a change of course after the passing of Cape Finisterre:—"This sudden alteration in the variation led us fifteen miles to the east of our course, so as to make Ushant on our port bow."

Again, as to *differences* in the deviation *on different voyages*, the same register affords some curious facts. Thus, on the outward voyage in February 1848, just after the compasses had been adjusted, the variation by the standard compass, from the mean of three azimuths on a course S. 2° W., correct magnetic, (the ship being 60

miles E.N.E. of Cape Finisterre) was 21° 26′ W.; but on the next passage out, April 23, when half-way betwixt Cape Finisterre and Lisbon, steering, within the fraction of a degree, the same course, the variation, by standard compass, mean of three azimuths, was only 10°. A somewhat corresponding change is noted by the captain, in the comparative indications of the port binnacle and the standard compasses.

A comparison of azimuths taken on the passages, *outward* and *homeward*, give further instructive results. Thus, whilst the azimuths taken on *certain courses* agree very well on different voyages, those on other rhombs, though taken in corresponding positions in the voyage and with the ship's head in the same direction, differ widely; and whilst the observations for the variation on various portions of the outward passage correspond nearly with those made on the reverse course homeward, other observations made in a different part of the passage give differences, occasionally, of ten or twelve degrees betwixt those made in the outward and homeward progress.

These discrepancies, however, allowing for the necessary defects of azimuths when the ship has much motion, might possibly be considered as referable, mainly, to the residual error of the standard compass after the application of magne-

tic "correctors."* For it is but justice to Captain Moresby to add, that the observations on certain courses, when separated into classes, exhibit such a notable measure of agreement as to give decided indications of the observations, generally, having been carefully and skilfully made.

A candid and careful enquiry into the action of the compasses in the cases described in this section—relating to a class and line of iron-built steam-ships in which all the appliances at present in use for the adjustment of the compasses seem to have been skilfully adapted—must altogether fail in justifying the conclusion which some have arrived at, that "the practical difficulty of correcting compasses for iron ships is overcome, and that they are as safely navigable as timber ships."

This most obviously, *as far as dependence on compass guidance goes*, is not the fact. For we find even from the favourable examples of a line of ships so admirable in all their appointments, instances of sudden changes in the compasses, and of frequent discrepancies in their action, altogether unknown in timber-built ships; besides residual errors, after all the means taken for their adjustment in ships of iron, considerably

* The correcting agency employed in this ship, the Ripon, consisted of two magnets with iron chain for each corrected compass.

larger in amount, and more perplexing in their nature, than the total uncorrected errors produced by the local attraction on almost any judiciously planted standard compass in ships constructed of wood. Yet this sort of comparison of compass performance, drawn from the case of ships employed in navigation within a moderate range of magnetic latitude, will be found to be far less favourable as we proceed in our following sections to further elucidatory examples.

SECT. III.—*Illustrative Cases of extraordinary and dangerous Defectiveness of Action in Compasses magnetically adjusted.*

WHEN I first undertook to show the defectiveness, in principle, and the danger, in practice, of the method proposed for the correction of the local attraction of iron-built vessels on the steering compass, by means, in part, of fixed permanent magnets,—I was not acquainted with any actual results of such defectiveness. On the contrary, reports had been prevalent which seemed to be generally in favour of the successfulness of the method of correction devised.

Subsequently, however, facts have been elicited, from time to time, which serve abundantly, I think, to bear me out in all the objections which I had conceived against the efficacy of the exist-

ing plans of adjustment. Of examples of this kind, the following may serve for illustration.

1. *Case of the Nemesis, iron steamer:* from England to China, in the year 1840. Commander W. H. Hall, R.N.

The Nemesis, 700 tons burden, with engines of 120 horse-power, was the first iron steamer which proceeded round the Cape of Good Hope. Her length was 184 feet, over all; her breadth 29, and depth 11 feet.

For the neutralizing of the local attraction on the compass, this vessel was fitted with magnetic correctors, but not under the superintendence of the inventor of this mode of adjustment, nor exactly according to his system—the box of iron chain not being employed. The experiments for the original adjustment, too, were conducted at Liverpool under great disadvantages; but still such reliance was placed on the correcting arrangements, as proved all but fatal on the second night after sailing. The ship, misguided by her compasses, struck heavily on a rock, lying at the entrance to the Bay of St. Ives, not far from the Land's End, Cornwall. Fortunately, she had struck the mere edge of the reef, and passing over it, was kept afloat inside till the daylight enabled the captain to extricate himself from his perilous position.

The ship being afterwards swung at Portsmouth, her compasses were readjusted, and their errors found to be greatly modified. But though the large magnets were never moved, nor the position of the compass changed, during the voyage round the Cape, the errors became greatly increased. Such, indeed, were the discrepancies of the compasses, that the utmost anxiety was always felt on board the vessel when near land. In the Mozambique Channel, especially, this source of anxiety was extreme; and wherever any nicety of course was requisite, "it was always found the safest course," says Mr. Bernard, in his Narrative of the Voyages and Services of the Nemesis, "not to put faith in the compasses at all."

From this particular case, however, in which the magnetic arrangements, it is evident, were very defective, it would neither be candid nor justifiable to attempt to draw any decided conclusions; especially, as in several other cases of vessels proceeding into the same regions, the compasses, properly and carefully adjusted, are reported to have acted satisfactorily. But, on the other hand, it should be observed, that several other cases are well known in which far better adjustments of the compass in iron ships have failed to afford either safe or satisfactory guidance in voyages into the southern hemi-

sphere, and some instances in which the adjusted compasses have greatly and dangerously changed.

2. *Case of the Honourable East India Company's iron pilot-brig, Fame:* from Glasgow to Calcutta, 1844-5. Captain John W. Lewis.

The original paper, forming the basis of the present chapter, had been announced for communication to the physical section of the British Association at its meeting in Oxford, in 1847, when I happened to learn that Colonel Sykes, who felt much interest in the subject as a matter of important practical science, was in possession of valuable information thereon. This information being freely committed to my use for the illustration of my paper, I avail myself of it likewise for the object now before me.

The principal document, kindly furnished me by Colonel Sykes, consisted of a tabular journal, kept on board the pilot-brig Fame, of Observations on the steering-compass as compared with the results obtained by sights with the azimuth compass,—the discrepancies in which were very large and remarkable. The binnacle-compass, I was informed, had been adjusted by neutralizing magnets, on the principle of Mr. Airy, but not in any way under his direction.

The table of observations in this case of the

Fame, commences immediately after the ship had crossed the line. The discrepancy betwixt the steering-compass and the true magnetic direction, when steering S. 40° W. (by azimuth compass) was, in latitude 20° S., 5° westerly. In latitude 24° 35′ S., steering S. 11° E., the error of the compass is stated to have been 11° easterly; and in 27° 8′ S., the day following, steering S. 9° W., the error is registered at 13° westerly.

Whilst the ship was pursuing a south-easterly or easterly course, the error continually increased. During four days run within the 40th parallel of south latitude, and on courses S. 76° E. to S. 80° E. (correct magnetic), the errors are noted at 48°, 55°, 55° and 57° easterly. From that parallel steering to the north-eastward, the errors were found to change in the reverse order,—so as, betwixt latitude 30° 44′ S. and the equator, to diminish from 15° to 6°.

In the same journal are registered two sets of observations on the errors of the steering compass, as ascertained, in succession, on a variety of courses, whilst the ship was navigating within the 36th and 37th parallels of southern latitude. From these registers, the maximum residual error of the "adjusted" binnacle-compass, on a course S. 8° W., appeared then to have amounted to 22°,—the points of change being S. 45° E. and N. 45° W.

From a report by the captain of the performance of his compasses on this occasion, I take the following characteristic extract:—

"In regard to the compasses," he says, "I detected no error until I got near the equator, but after passing the same, the error immediately encreased to a point and a half; and in running my easting down at *certain times*, and under *certain circumstances*, the error would increase to four and three-quarters points. As I made northing, the error gradually decreased; in crossing the S. E. Trades, the error was not more than a point and a half; when arrived again in north latitude, only half point, and on reaching the Sand Heads, the entire error was only four degrees."

3. *The iron ship Three Bells:* from Glasgow to Australia.

This is a very recent case of very erroneous compass action, mentioned to me by a friend. The information communicated is indeed very limited as to particulars and circumstances; but sufficiently explicit as to the great and principal fact. Adjustment had been made at Glasgow of her steering-compass by means of artificial magnets acting antagonistically to the ship's attractive and deviating influence. This adjustment, however, eminently failed in southern

latitudes. At Port Adelaide, the captain tried his compass and found a deviation, with the ship's head *west*, of two points westerly, and with the head *east*, a corresponding error, easterly. It is quite probable that had there been no correctors the compass might have acted with greater precision, and undoubtedly with less embarrassment to the navigator and less risk to his ship.

4. *Various cases of iron-built ships*, not navigating southward of Alexandria, of the dates of 1845 and 1846.

The cases, under this head, are derived from another document furnished by Colonel Sykes. They are reported in abstract by an officer connected with the Peninsular and Oriental Steam-Navigation Company, but are not sufficiently specific for individualizing in the present use of them. The vessels particularly referred to are the Pacha, Madrid, Queen, and the ferry-boat Gipsy. The compasses of three of these vessels were adjusted, it appears, by antagonistic magnetic forces, arranged by opticians in London or Glasgow. The box of chain is particularly noticed, in one of the cases, and was employed, it is presumed, in the other sea-going vessels. None of the compasses, in these various instances, appeared to have acted correctly; on the con-

trary, generally, in an unsatisfactory manner. Errors of various degrees of magnitude are specified in each case, and, exactly as I have anticipated from theory, errors varying from time to time in their quantities. In one case, it is mentioned, that the captain of the vessel complained, on his arrival at Southampton, that his compasses were incorrect. On the vessel being swung, an uncorrected error of a point was found. Subsequently, and at intervals of time, the experiment was twice repeated, when the errors seemed to be increasing.

In another instance, that of the Pacha, it is stated—also accordant with theory—that the errors of the compass seemed to have gradually increased whilst on the outward voyage, till, at length, the compass indications became so unsatisfactory, that, on the homeward passage, an attempt was made by the captain to re-adjust the magnets,—an attempt which, as might be supposed, altogether failed.

The writer of the brief report mentions the fact of the iron-chain, used for a part of the corrective instrumentality, being found to have become much rusted. This circumstance, however, could not affect its proper operation. Nor could the want of permanency in the magnets employed, which is also noted as a probable occasion of error, serve to explain the several

discrepancies observed. The action of principles, however, so much and so frequently referred to in the foregoing pages, may be seen to be abundantly adequate for the elucidation of each and every particular error and change.

5. *Instances of irregularity of action in the "corrected compasses" of iron-built steamers employed in our coast navigation.*

From the experiments heretofore detailed, we have inferred, that an iron-built ship, magnetized in the process of construction, should change its magnetic axis, and consequently its influence on the compass, when vibrated by the action of the engines, or strained by passing over a rough sea, whenever the ship's head should be in a contrary or different position from that in which the magnetic power was originally developed, or more recently readjusted.

This deduction from analogy has been consistently supported by my own experience—so far as a very few voyages in iron-built steamers, within the Irish Channel, could be expected to apply.

In one instance, proceeding from Cork to Liverpool, I made enquiries of the captain as to the action of his compasses under the neutralizing influence of correcting magnets. He told me, in general terms, that his compass acted "very well."

But, on special investigation of the case, I found my own views entirely supported. "Your compass," I remarked, "you say acts very well. But, let me ask, will any direct course from place to place, serve, by taking the opposite course, for the return? In other words—if, on an *east* course, you can proceed direct from the Tuscar to Holyhead, can you, on a *west* course, go from Holyhead to the Tuscar?" "Oh, no," was the reply;—"we have to make some allowance." "How much?" I enquired. "Perhaps half a point each way."

On a passage, again, from Glasgow to Liverpool, in one of the beautiful iron steam-ships traversing betwixt these two great commercial ports,—I made similar enquiries of the officer in command. He likewise told me that his compass was very well corrected, and performed very well. "But," I asked, "does it act *quite* correctly? Are your courses up and down the Channel exactly opposite courses? Can you steer exactly by the courses taken, with reference to the compass directions, from the chart?" His reply was to the effect, that he could not: then, adding, "*we require to make allowances* - to the extent of, perhaps, a quarter of a point."

Enquiries, I may add, made of other persons, practically familiar with the navigation of iron ships, or information obtained in other forms,

tended to support the conclusion of the generality of such deviations of compass action.

6. *Case of the iron-built ship Equador, illustrative of change of deviation produced by a heeling position.*

Captain Shannon, subsequently in command of one of the ships of the British and North American Steam-Packet Company,—had charge of the Equador during the latter part of a voyage through the Strait of Magellan into the Pacific. I did not obtain any particular information on the general discrepancies in the indications of the "corrected compass," but only as to the change which took place when the ship was in a heeling position. In such cases, Captain Shannon stated, the compass was affected in a most extraordinary manner—being so erroneous, and so variable in its indications, even whilst steering on the same course, that their progress along the South American coast, became very perplexing. As a general remedy, by the way of diminishing the extent of the error, the ship had to be kept under low sail, so as to be as nearly upright as possible.

This effect of a great heeling position, was confidently anticipated; though the extent of the varying influence seems, in this case, to have been greater than had been supposed likely.

7. Cases illustrative of *the straining action and bending tendency of heavy seas* on the ship's hull.

The reality of such an action and tendency is, on mechanical principles, obviously demonstrable. But the extraordinary degree of force exerted on a ship labouring and plunging in a heavy sea, by the rapidly varying surface of the supporting fluid and its large and singular undulations, may not be undeserving of illustration. Of the unimagined force thus brought into action, some well-known special cases of iron-built vessels, which instructively served for the guidance of our intelligent builders of iron ships, may be adduced as examples.

The case of the Nemesis, the steamer already spoken of, affords a striking illustration of the bending action of heavy seas. During a gale of wind, after passing round the Cape of Good Hope, so violent was this action that the upper works of the ship actually parted, the iron plates, forming the substitute for planking, ripping downward on both sides to an extent of some feet, and the entire fabric threatened with breaking in two. In this awfully perilous condition, the fatal tendency of the damage was arrested by the extraordinary exertions and ingenious contrivances of her commander, Captain Hall. His plan, in the first instance, was this:—having passed the ends of the ship's cabin cable through the hawse-holes

forward, he extended them along the deck aft, and secured them through the rudder-trunk; then stretching the bight with a heavy strain upward, by tackles attached to a pair of sheers amidships, the extremities of the ship became so well sustained by this *elevating support* as to arrest the progress of separation and threatening destruction. By subsequently bolting large clogs of timber to the vessel's upper-works, inside, the weak gunwale was so strengthened as to be found quite effective for security and safety, and for enabling the previously all but foundering craft to do excellent service in the China war.

The case of the *Elberfeld* affords a still more startling example of the bending tendency of heavy seas to which we refer. The Elberfeld—a vessel of great length for her other dimensions, and not built, I apprehend, for ocean service—set out from Brielle, bound for the Thames, in the morning of the 22d of February, 1844. In the afternoon of the same day, the wind blowing a brisk gale, the ship was observed by an intelligent passenger, Mr. Bush, to be working in her hull in an unusual manner. He had but just announced the fact, and his suspicions thereon, to Captain Stranack, when the ship began to separate; and so rapid was the work of destruc-

tion, that in a few minutes the sea made its way in-board, the boiler burst, on its contact, by collapse, and the vessel went down as if stimulated in its descent by the loud explosion! Happily, but few persons were on board, 16 only in the whole, of whom, as essentially aided by the promptness and activity of Mr. Bush in getting off the boat, 13 escaped, and three, consisting of two stokers and the cook, perished.

These cases may suffice to elucidate our assumption (pp. 286—290) of the straining tendency of the waves being such as to be calculated to produce in iron ships a modifying influence on their magnetic distribution, with a corresponding change in the action of their compasses.

SECT. IV.—*Cases of calamitous Losses in British Shipping, referable to the Errors of the Compass, by reason of its local attraction.*

BEFORE the employment of iron as the principal material in ship-building, there was always a quantity of this metal to be found in and about the structure sufficient to produce a deviating action on the compass in almost every ship. But few observant and intelligent navigators could have failed to notice frequent discrepancies betwixt the ship's position as indicated by the most carefully kept reckoning, and that determined

by celestial observations or the making of land. These differences, however, not being generally understood or carefully investigated, the knowledge of their prevalence did not avail, ordinarily, for beneficial guidance. Errors of position produced by ordinary defects of navigation—such as bad steerage, inaccurate logs, defective allowances for leeway, tides or currents, etc.—were not unlikely, in the long run, to be mutually corrective; but the errors due to the deviation, regulated by the laws of attractive influences, and acting on like courses in the same way, necessarily tended to a more decisive and dangerous misguidance. Hence, besides the many hair-breadth escapes to which navigators, at all periods of our naval history, have been exposed from ignorance of the deviation, there can be no doubt but that some of the most dreadful shipwrecks which are to be found recorded in our naval annals are to be ascribed to the same cause. As illustrative of the importance of our subject in its bearing upon the perils of sea-adventures, I may here repeat the mention, though now a somewhat old story,* of some striking cases of very disastrous consequences, having, as I am well persuaded, resulted from

* The illustrations of this section, for the most part, were originally drawn up for a lecture on the "Deviation of the Compass," delivered at the Royal Institution, at Liverpool, January 23d, 1822.

ignorance of, or inattention to, the deviation of the compass.

A fleet of sixty-nine sail of merchant-ships, bound to the West Indies, sailed from Cork under the convoy of His Majesty's ships Carysfort and Apollo, on the 26th of March, 1804. Early in the morning of April 2d, when by their reckoning they were about 100 miles from land, the Apollo, to the amazement of every one on board, struck the ground. At daylight, many other vessels were found to be in a like disastrous condition,—on shore on the coast of Portugal, as it proved, near Cape Mondego. It is unnecessary for me to detail the sad events which succeeded, excepting the general results of this dreadful accident. The Apollo being at a distance from the beach, and the gale continuing for three or four days, lost sixty of her crew, who perished from cold, drowning, hunger, and other circumstances connected with their perilous situation. Many adhered to the wreck for about sixty hours, sustaining during this period the most intense anxiety and severity of suffering from cold, wet, and exhaustion, without either meat or drink. Along with the Apollo, twenty-nine sail of merchantmen were likewise wrecked; some of these foundered with all hands, and most of the others lost from ten to twelve men each. The total loss of lives has been estimated at 250 to 300 men.

This fatal accident was very generally ascribed to the carelessness and inattention of the Commodore. He was, no doubt, chargeable with defect in that prudent and watchful jealousy of mere compass guidance, which, under Providence, is one of the best safeguards in practical navigation; but the disaster, to my mind, is plainly and reasonably traceable to the (to him unknown) influence of the local attraction. For we know that the deviation in ships of war, on a course S. 29° W., and distance of 700 miles (the course and distance betwixt Cork and Cape Mondego), would, in very many cases, produce an error of more than a degree of longitude!

An officer, from whose narrative the particulars of this calamity were derived, mentions the fact, that no one on board the Apollo expected the ship to be near land, and that, when the ship struck, they imagined they were upon some unknown shoal.

Of a nature somewhat similar, but vastly more calamitous, was the loss of His Majesty's ships, St. George, of 98 guns, Defiance, 74, and Hero, 74, in the winter of 1811-12.

The Hero, Captain Newman, with the Grasshopper sloop, Captain Fanshawe, sailed, December 18th, 1811, from Wingo Sound in the Cattegat, with the Egeria and the Prince William, armed ships, and a convoy of 120 sail. This vessel,

the Hero, instead of standing well to the westward, to compensate for the deviation and the action of a north-westerly wind, steered the direct compass-course for the Downs; and having, in the night of the 23rd, separated from most of the convoy, she struck the ground in a heavy squall of wind and sleet, upon the Haak Sand, near the Texel Island. Some of the convoy which kept by her shared the same fate; but the greater part, aware, apparently, of the danger into which they were running, hauled off to the westward and escaped. The Hero, after enduring the violence of the concussions against the ground during the night, was seen in the morning totally dismasted, and lying on her beam ends. She soon went to pieces, and the state of the weather preventing assistance reaching her, all the people, with the exception of eight who were washed ashore, perished with her.

Though thus stranded on the coast of Holland, the captain, it appears, was so confident of his being sufficiently removed from that shore, that when the ship was found to be in danger, he ordered her to be steered to the S. or S. S. E. (a course leading directly upon the sand), from the supposition that he was upon some shoal on the British coast! Surely a person entrusted with the command of a line-of-battle ship, could not be so ignorant of the common rules of navigation as to fall into such a disaster by a mere

blunder, especially when different persons in the ship must have kept a reckoning, and mutually secured themselves against such a chance of error. There was doubtless a great want of prudence shown by the Commodore, yet I imagine that the *deviation*, which, doubtless, he had neglected to take into the account, was the true and essential cause of the sad catastrophe.

It was a curious circumstance in the history of this disaster that, whilst a ship navigated by men of superior nautical education, and commanded by a post-captain of the British Navy, was, by mistake of the ship's position, actually run on shore,—the general fleet of merchantmen, though subject to an extra risk in their duty of following the Commodore, navigated, for the most part by slightly educated, but *practical*, seamen, escaped.

A striking instance of the availableness, for safety, of practical knowledge and shrewd observation, was elicited, on this occasion, by a Mr. White, a plain intelligent experienced seaman of Whitby, who was employed as a pilot on board of one of the transports, I believe the Centurian. On the fatal day of the accident, Mr. White, whilst occupied below in taking refreshment, was informed that the Commodore, who had previously been steering a somewhat scant course, as it was thought, for his destination,—had made the signal to steer S. S. W. "Haul our ship up to S.W.," was the prompt and

authoritative reply of the intelligent pilot, who, in the quaint language of the sailor, remarked solemnly to the officers around him in the cabin, —"*if they stand that way they will all sleep in their shoes before morning!*" This prediction, as we have seen, was awfully fulfilled, whilst Mr. White, daring the responsibility of disobeying orders, and resisting or overcoming, by his firmness, the authority of the government agent on board (a circumstance to his ship involving peculiar and additional difficulties in independent action), saved himself, the ship entrusted to his pilotage, and his companions in adventure. He, indeed, knew nothing scientifically of the local attraction of the compass; but he knew from experience that *something* always tended, in the performance of this passage, to carry the ships towards the Holland coast.

The St. George and Defiance were circumstanced a little differently. The former, under Admiral Reynolds, had been dismasted in the Baltic, but being refitted and considered capable of performing the passage, she made the attempt, accompanied by the Defiance. Unfortunately they steered a direct compass-course, and being overtaken in the same gale under which the Hero suffered, both ships went on shore on the western coast of North Jutland. Of the crew of the Defiance, which went to pieces half-an-

hour after striking, only six men were saved, who got to shore on pieces of the wreck. Eleven of the crew of the St. George most providentially escaped in a similar way; "and when the last of them left the ship, on the afternoon of the 25th, the admiral and captain were lying dead beside each other on the quarter-deck, together with the greater part of the crew. Only about fifty remained alive, whose cries were heard till it was dark. The ensuing night terminated their sufferings."

The number of persons that suffered in these three ships, including the whole of the officers on board, amounted to nearly 2000, being a greater loss of life in British seamen than has occurred in some of the most splendid battles in which our fleets have been engaged.

Under circumstances, I believe, somewhat similar to those of the Hero, was lost the Minotaur, of 74 guns, Captain Barrett, on the Haak Sands, at the mouth of the Texel, on the night of the 22nd of December, 1810. She left Gottenburg on the 15th, in company with the Plantagenet and the Loire, with sixty sail of ships under convoy, in tempestuous weather. During the gale, she separated from the ships in company, most of which, if not all, made their escape. One hundred and ten of the crew of the Minotaur succeeded in saving themselves in

the boats; the remainder, about 360 in number, perished.

Towards the production of all these appalling calamities, the deviation of the compass, I am persuaded, greatly and essentially contributed. In the case of the Apollo, we have shown that an error of above a degree of longitude in her calculated position might be probably ascribed to the local attraction. In the case of the Hero and Minotaur, an allowance for deviation of no unusual quantity for timber-built ships, might, in its ordinary mode of action, amount to twenty miles of error, or more, in the distance from Bovenbergen, on the north-west coast of Jutland, to the southern coast of England. Such an allowance, made on the courses of the ships referred to which were lost on the Haak Sands, for the south-eastward deflection by the local attraction—an allowance which the wind, at the time, would have amply admitted—would have carried them considerably to the westward of every danger, and the two ships of war, the Hero and Minotaur, with several transports, and above a thousand men, would have been saved.

As to the other case (the St. George and Defiance), I am not sufficiently acquainted with all the circumstances as to justify any confident assertion concerning the operation of this baneful influence towards the production of their terrible loss; though it seems exceedingly probable that,

had their commanders been fully aware of the eastward tendency of the influence acting so insidiously on their compasses, they might have taken a better offing and so escaped the fatal result.

To these examples so destructive of human life we might have added others of more modern date, and especially of cases bearing happily on the loss only of property. As for instance, the stranding of Her Majesty's steam-sloop Sphynx (though afterwards recovered) on a reef of rocks on the south side of the Isle of Wight, in the morning of the 6th of February 1847, which we merely refer to as a well-known case belonging to a numerous series of disasters resulting from unapprehended errors of the compass.

On the whole, we may conclude, I think, in considering the truth of a position, we have more than once assumed, as having been established, viz. —that the danger to life and property in seafaring adventure from misguidance by the compass, does not depend so much on the defects or uncertainty of the indications of that important instrument, as on ignorance of, or inattention to, the fact on the part of the navigator. And it may be confidently asserted, that as to many of the cases in which a mistaken confidence in the compass guidance has led to fatal catastrophe, the ships might probably have proceeded safely

to their destination had they had no compass at all on board. For that, in this latter case, the risk would not be *excessively* increased, we infer from the well-considered conviction, that the experienced and able navigator would not hesitate, if there were a needs-be, to take charge of a ship for any destination on the face of the globe even if deprived of all compass guidance whatever. In such an undertaking, however, for the meeting of the unusual difficulties, and the avoidance of particular perils, he would require *time* for his voyage,—*extra time*, as a voyage performed under such great disadvantages must not be one of haste.

Sect. V.—*The Birkenhead Troop-Ship.*

In treating of the subject of fatal results connected with erroneous compass action,—the case of the Birkenhead is naturally suggested as one fitting for particular consideration. Not to discuss, indeed, the question which belongs not to my province here, of how far, or in what degree, the sad catastrophe might be referred (as some have referred it) to mistake, imprudence or neglect on the part of the officers of the ill-fated vessel,—a question to which the fate of the dead, and the feelings of their kindred and friends give a peculiar character of delicacy,—it will be my object simply to show, which I hope to be

able to do satisfactorily; that had there been *no* unapprehended compass error, or no delusive reliance on compass guidance, the Birkenhead might yet have been floating gallantly, and some 430 or 440 souls, suddenly swept into eternity, might yet have maintained their lot among the living. For hardly was the ink dry in which the danger to the navigator of iron-built ships from compass-irregularities and changes had been set forth in a foregoing section, when this sad case was announced, proclaiming, as to me it seemed, with impressive emphasis, the extreme importance of the subject (publicly and nationally considered, as well as privately and commercially) on the investigation of the principles of which I had spent so much labour, and in my endeavours to call the public attention thereto, I had been so urgent.

Well known as the leading circumstances of this melancholy event have become, it will be convenient for illustration, and may be interesting to the general reader, before entering upon the scientific enquiry, to give a brief description of the Birkenhead, and of the voyage and object on which she was last engaged.

The *Birkenhead* was one of a class of iron ships originally designed for frigates, but, because of doubts arising as to the fitness of this material for war purposes, had been converted into a troop-ship. She was built at the place whose

name she bore, by Mr. John Laird, and launched in December 1845. Her length between the perpendiculars was 210 feet; breadth 37 feet 6 inches; depth of hold 23 feet; capacity, carpenter's measurement, 1400 tons. The weight of her hull on being launched was found to be about 903 tons. She was considered of great strength in thickness of plates and size of frames; and, with a view to safety, her hold was divided, by athwartship bulkheads, into eight compartments—which, with subdivisions in the engine-room, made altogether twelve water-tight sections. Her engines were 564 horse power. At sea, when only duly loaded, she was considered an easy, fast, and commodious ship. For adapting her for a troop-ship, it may be noticed, a poop and forecastle were added to the original structure.

For some time, after being launched, she was laid up, but eventually employed on various public services on the British coasts, and in the carrying of troops to the Channel Islands, Lisbon, Halifax, Cape of Good Hope, etc.

The Birkenhead, under the command of Mr. Salmond—an officer whose abilities and conduct as a master in the navy had gained for him general approval and commendation—proceeded from Cork on her final adventure in January last (1852), with reinforcements of troops for the Cape. After a forty-seven days' passage, she

arrived out at Simon's Bay, on the 24th of February. Hastily disembarking some women and children, replenishing coals and stores, etc., she proceeded again with, it is calculated, somewhat more than 630 souls altogether on board, under orders for Algoa Bay and Buffalo Mouth, to land the drafts of the different regiments. The weather was fine and calm, and sea smooth, when at 6 P.M. of the 25th, this splendid ship steamed out from her temporary anchorage. At 8 P.M. their position within False Bay, was duly pricked off on the chart, and a course shaped along shore, S.S.E. ½ E., calculated, it was assumed, to take them abundantly clear of the coast in advance. Under this course, with cautionary directions to the helmsman "not to go to the eastward of it," they appear to have passed Cape Hanglip, about 9½ P.M. at the distance (according to Captain Bunce's report) of four or five miles. The night was starlight and clear, and the land constantly in sight from three to four points on the port bow. From documents brought before the public it would appear that Captain Salmond, after having been on duty almost incessantly for above thirty hours, had retired about 10 P.M., and unfortunately, as these papers intimate, the second in command also. A few minutes before 2 A.M. of the 26th, the ship going on her course, with an apparent free sea around her, the leadsman on the paddle-box got soundings in twelve

fathoms;—before he could get another cast, after announcing the fact, she struck on a sunken rock. The force of the concussion, with a body of about 2000 tons weight and a speed of above eight knots, was necessarily disastrous. Whilst the engines were being turned back, a second stroke on the engine-room bulged in the side and tore open the bottom there. Two, at least, of the larger compartments, forward, being thus opened to the free flow of water, the strain of so much unsupported weight of iron caused the ship to rend across just before the paddle-box.

Within half-an-hour from first striking (some accounts make the time considerably less), the two portions of the wreck fell asunder in opposite directions, and sank. The women and children had, during this brief interval, been duly cared for, and placed in a boat—a portion of the crew and passengers escaped along with them, and in other boats—and others by swimming, or being supported on portions of floating wreck, survived till afterwards picked up,—and thus yielded an amount of about 193 of those saved, whilst the greater proportion, about 438 persons, including the principal officers, sank and perished with the ill-fated vessel.—But we must now turn to the considerations designed by the introduction of this sorrowful narrative.

The rock on which the Birkenhead struck was one of those stretching seaward from the place

ominously called *Danger Point*, lying midway betwixt Capes Hanglip and L'Agulhas.* The direction (correct magnetic) of the rock from Simon's Bay appears to be just S.S.E. ½ E., and the distance about 55 miles, or, from Cape Hanglip 31 to 32 miles. Passing Cape Hanglip at the distance of a mile, this course would not have been sufficiently far to the southward to clear the rocks; but at four or five miles distance (the position asserted), the danger should have been cleared by an interval of from two to three miles;—or, under the charge to the helmsman "*not to come to the eastward of his course*," a full three miles, if not more, ought to have intervened betwixt the rock struck upon and the place of the ship in passing it. Hence the course actually made must have been S.E. *b* S., differing from that indicated by the compass about half a point—an error which, considered under the guidance of the foregoing researches, with the anticipations founded thereupon, is reasonably, and, I think, plainly referable to change in the compass direction taking place on the advance into the southern magnetic hemisphere and change of course. The change with respect

* To one of the elder brethren of the Trinity House, Captain Bax, I am indebted for a neat and careful tracing of a chart of the region of disaster, as well as for some interesting strictures by means of which I have been enabled to examine this case with particular advantages.

to the course, indeed, might not have been considerable; but, with respect to the influence of terrestrial induction, as urged by mechanical vibration or straining, in a direction so greatly altered, a change might be looked for in the ship's action on the compass, *beyond* what could be met by any existing plans of adjustment. This *might* have been discerned beforehand, perhaps, and, had a due suspicion of compass misdirection been entertained, must have been guarded against; but the change not being observed, the presumption of accurate guidance by the compass proved fatal. That the course shaped, for passing at night so dangerous a place in their track, afforded too narrow a limit; that the desire of shortening the distance, (the risks of which, as already urged, one cannot too strongly deprecate,) led to a too close hugging of the land, — must, to every prudent navigator, be obvious; yet the proposition originally enunciated remains unshaken, viz., that had there been no compass misguidance, the Birkenhead might still have been unmarked and unknown in the annals of maritime catastrophes.

END OF VOL. II.

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